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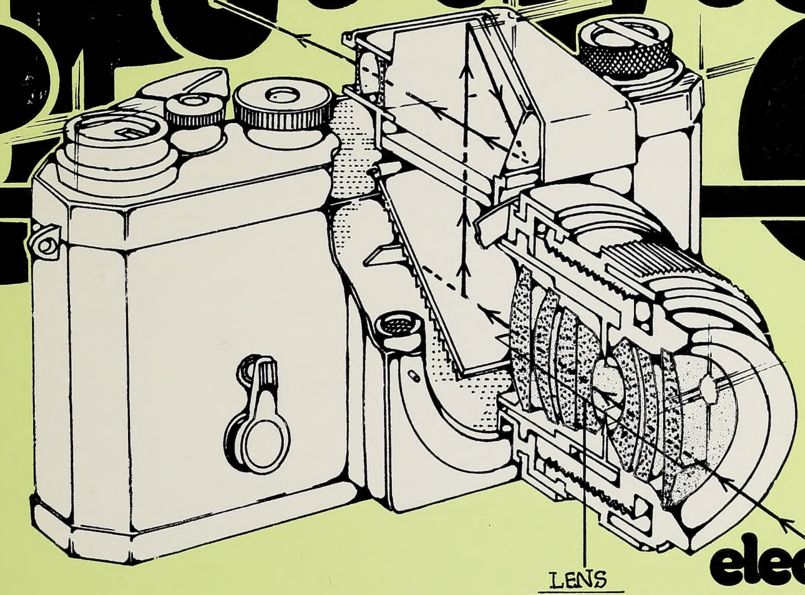

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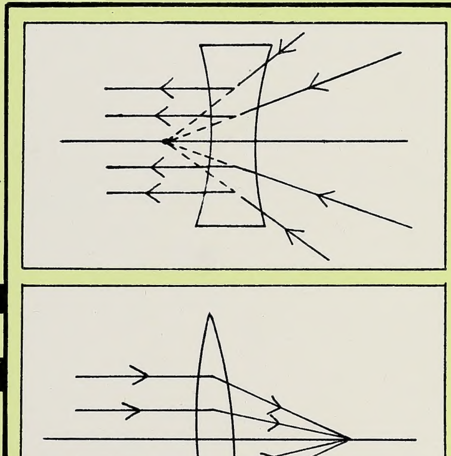

ALBERTA CORRESPONDENCE SCHOOL
ALBERTA EDUCATION
BARRHEAD, ALBERTA

CANADIANA
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Physics 30

Elective C

LESSONS 1C-4C

Distance Learning

Alberta
EDUCATION

Physics 30
Elective C
Lessons 1C-4C
Student Module
Alberta Correspondence School
ISBN No. 0-7741-0631-X

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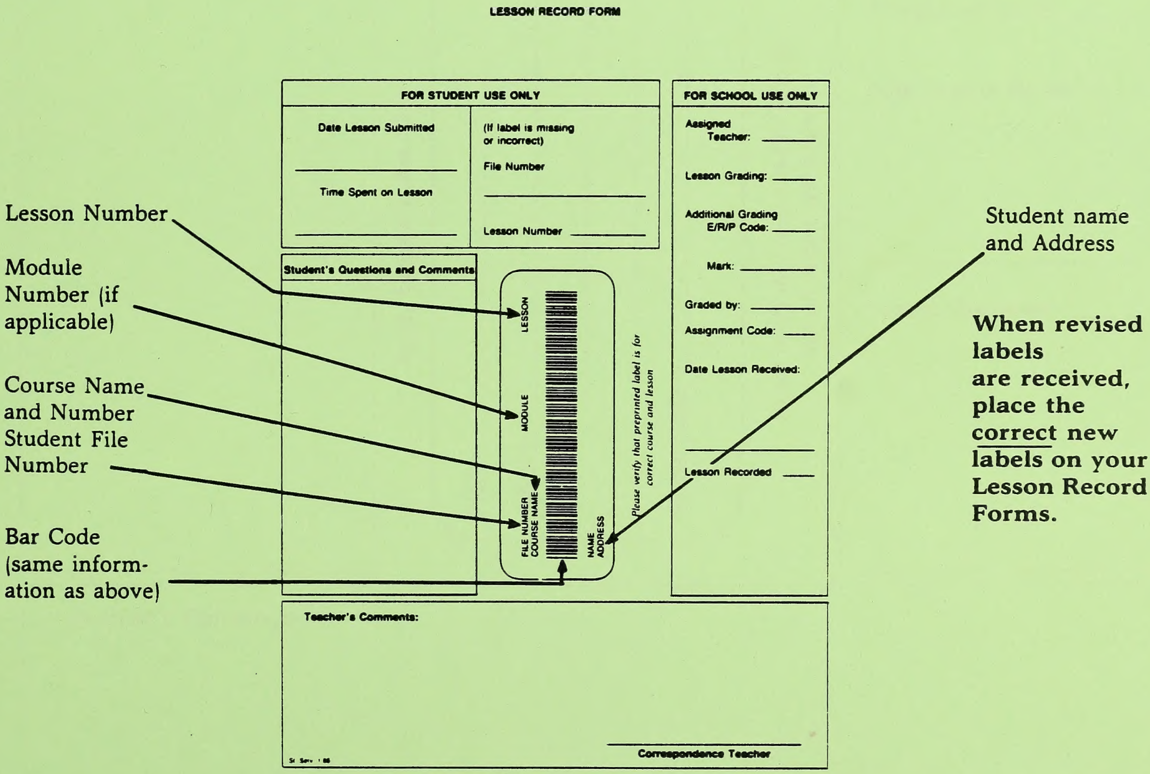

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Lesson Number __________

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Teacher: __________

Lesson Grading: __________

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ALBERTA CORRESPONDENCE SCHOOL

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(2) All exercises are completed. If not, explain why.
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(4) The Lesson Record Form is filled out and the correct lesson label is attached.
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Note: Optics will be done in lessons 2c, 3c and 4c.

BASIC ELECTRICAL CIRCUITS

All of the exercises for this lesson appear at the end of this lesson. At particular points in the lesson, the exercises that you should be ready to do are indicated. Do these exercises at that point in the lesson, and then continue your study of the lesson. When you have completed all of the exercises for this lesson, check over your work, and then send in the exercises for correction. Note that you do not have to send in the lesson notes; just send in the exercise pages.

Some Features of Electrical Circuits

Electrical circuits have many forms and characteristics, but it is possible to identify certain features that are common to all electrical circuits. Three such features are listed below.

1. Energy source to provide electrical energy.
2. A path which may be closed to allow electrical energy flow through it.
3. Some kind of opposition to the energy flow in the path.

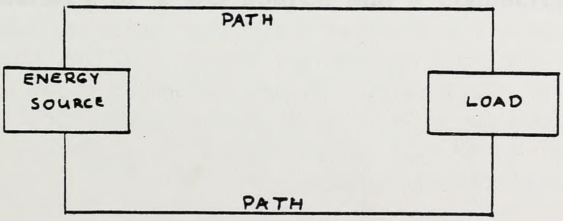
Generally, the energy source also may be called a source of EMF (electromotive force). Such a source might be a dry cell, a battery, or a generator. These sources of EMF usually operate by converting chemical or mechanical energy into electrical energy. There are some sources which convert heat or light energy into electrical energy, but such sources are not as extensively used as are the chemical and mechanical energy sources at this time.

In many electrical circuits, the path that the energy flows along is made of a metal called copper. The copper may be in a number of forms: a wire or cable; a rod or busbar; a thin layer of metal bonded to a non-conducting surface (as in printed circuits). Other metals (aluminum, silver, gold) may be used as part of the path, but copper is the most commonly used material.

Usually, the major opposition to the energy flow in a circuit is called the load. The path may provide some opposition also, but usually such opposition is much smaller than that provided by the load. The general name given to opposition in electrical circuits is impedance. However, in this elective, we will be concerned with a special kind of impedance called resistance.

We can now draw a simple diagram representing an electrical circuit. The diagram shows an energy source connected to a load through a path. Notice that there are two parts to the path, making it a closed path. This means

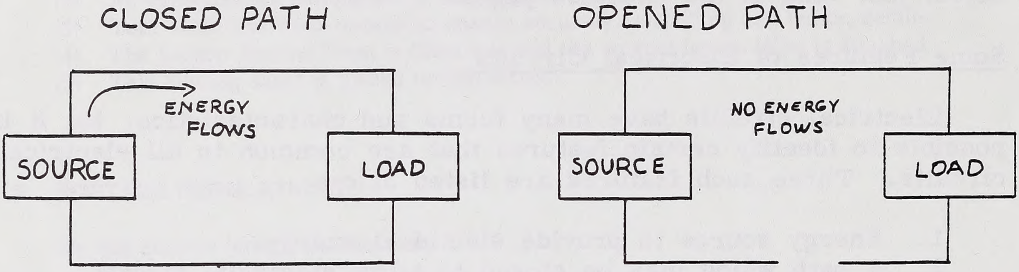
Fig A



that it is possible to trace around the path, starting from the energy source going to the load, then moving from the load and back to the energy source without going over any part of the path more than once.

In electrical circuits, it is necessary for the path to be closed for there to be any energy flow. If some part of the path is missing then energy flow will not occur, and the circuit is considered to be "opened".

Fig B



In order to represent electrical circuits, certain symbols have been accepted for use in electrical circuit diagrams. Some of these symbols appear in the following table.

TABLE 1

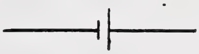
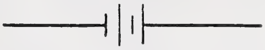
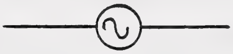
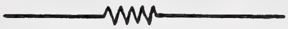
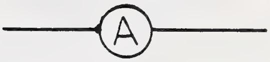
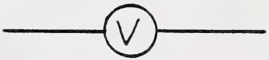
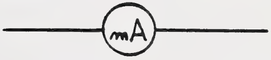
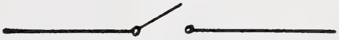
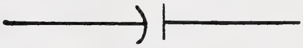
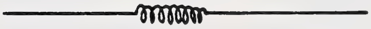
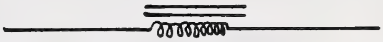
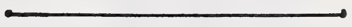
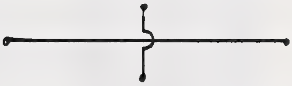
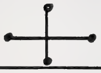
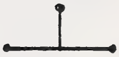
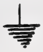
Name	Symbol
battery, cell, or DC source	  (longer vertical lines represent positive terminals)
AC source	
resistor	
Meters:	
ammeter	
voltmeter	
milliammeter	
Switch (in open position)	
Capacitor	
Coil or inductance:	
air core coil	
iron core coil	
Conductor:	
no connection	
connection	 
Ground	

Table 1 shows only a few of the symbols that are used. In this elective the symbols that will be used most are those representing a resistor, a battery or a DC source and a conductor.

Sources of EMF

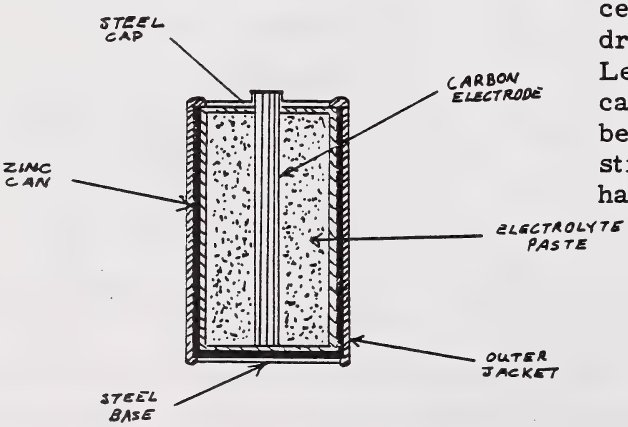
It was stated earlier that the source of energy in an electrical circuit may be called a source of EMF. EMF stands for electromotive force. What is EMF? Despite its name, it is not a force in the sense that the word usually is used in physics. EMF is a measure of the energy per unit charge provided by an energy source. In other words, the size of an EMF gives some idea of the work that can be done in moving a charge.

EMF is measured in volts. One volt is the EMF of a source that provides one joule of energy for a charge of one coulomb. In symbols, this can be expressed as shown below.

$$1\text{V} = \frac{1\text{J}}{1\text{C}}$$

Sources of EMF convert energy from some form into electrical energy. A common source of EMF is the dry cell, used in flashlights and portable radio receivers. Many types of dry cells are rated with an EMF of 1.5 V. Dry cells are classified as chemical sources of EMF. This means that they convert chemical energy into electrical energy. Energy stored in the bonds between atoms is released when chemical reactions occur. This energy may be used to move charges in a conductor; in other words, the stored chemical energy becomes electrical energy. A diagram illustrating some of the features of a dry cell appears to the left. A dry cell of the type shown (the Leclanché cell, or the zinc-carbon cell) normally cannot be recharged to its original strength after its chemicals have reacted for some time.

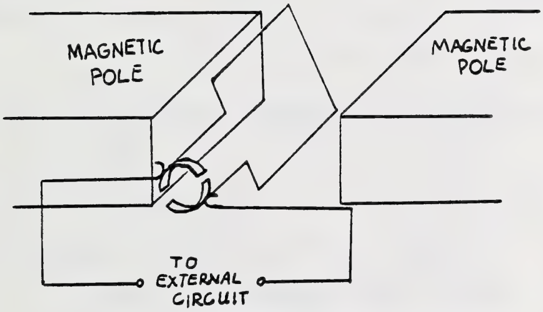
Fig C



Recharging involves applying another source of EMF that will reverse some of the chemical reactions, storing energy in the bonds. In the zinc-carbon cell, it is difficult to do this effectively. However, other types of dry cells can be recharged. An example of a type of rechargeable dry cell is the nickel-cadmium cell. Another type of rechargeable chemical source of EMF is the lead-acid battery used in vehicles.

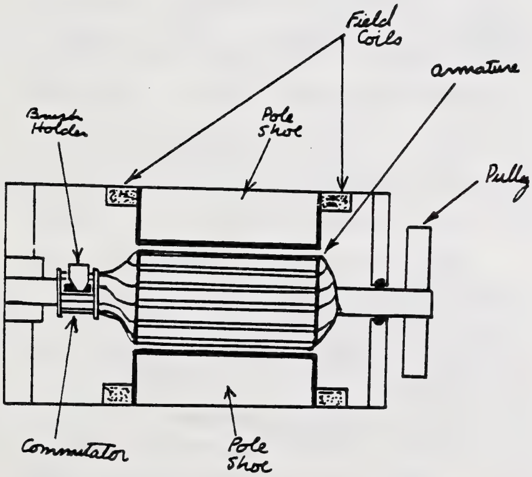
Many vehicles also have another source of EMF besides the chemical source. They use mechanical sources of EMF to provide electrical energy for various purposes in addition to recharging batteries. Mechanical sources of EMF convert mechanical energy to electrical energy. This conversion is accomplished through use of the principles of electromagnetic induction. As a conductor cuts or is cut by a magnetic field, an EMF will be induced in the conductor. Electrical generators use this principle to produce EMF. Mechanical energy is applied to the generator to produce relative motion between the conductor and the magnetic field. This results in an EMF being induced in the conductor. The EMF is made available in some way to circuits. A diagram illustrating a simple generator is shown to the left. The conductor is a single loop of wire which turns in a magnetic field. As the field is cut, an EMF is induced in the wire, and is provided to external circuits via the output terminals.

Fig D



Practical electrical generators usually have many loops of wire arranged in special ways to produce EMF. The diagram in Figure E shows some of the features of an actual electrical generator. The armature holds the loops of the conductor that cuts through the magnetic field. The magnetic field is provided through the field coils. A portion of the EMF generated is used to form an electomagnetic field between the poles (the pole shoes). The brushes, which remain in contact with the commutator as it turns (the commutator is mounted on the same shaft as the armature and is connected to the ends of the conductor loops), are connected to the external terminals to provide the EMF to external circuits. The pulley is connected to some mechanical energy source (such as a gasoline engine) via a belt.

Fig E



Chemical and mechanical sources of EMF are the major electrical energy sources in use at this time. There are a number of other sources that have limited use. Three of these, the piezoelectric, thermoelectric, and photovoltaic sources, are discussed briefly below.

The class of piezoelectric sources could be classified as part of the mechanical energy source, since they convert mechanical energy to electrical energy. However, as we shall see, they differ a great deal from the type of mechanical source described in the preceding notes. The piezoelectric effect is the primary feature by which piezoelectric sources may be classified. With the piezoelectric effect, a changing pressure applied to a particular kind of crystal will produce an EMF across the crystal. For example, if a piezoelectric crystal is struck by a hammer, it may convert part of the mechanical energy of the hammer to electrical energy. This electrical energy might appear as a deflection of a vacuum tube voltmeter's needle or as a brief glow of a bulb. Crystals of materials such as quartz, rochelle salt, and barium titanate will exhibit the piezoelectric effect. A common use of this effect is in the pickups of some record players. See Figure G. With such pickups, a needle or stylus rides in the record grooves. The motions of the needle are transferred to the piezoelectric crystal, twisting it. Plates on two faces of the crystal pick up the EMF. The pattern of EMF forms an electrical signal which is amplified by circuits in the record player, and is eventually sent to loudspeakers to produce sound which should be similar to that which was encoded on the record.

Fig F

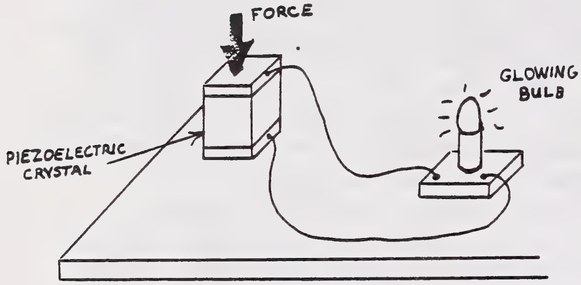
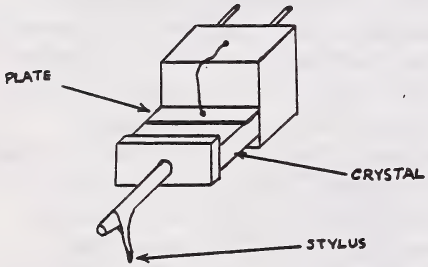
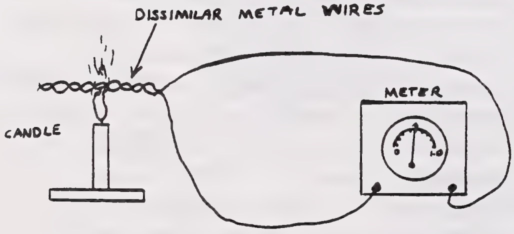


Fig G



Thermoelectric sources convert heat to electrical energy through the use of a device called the thermocouple. A simple thermocouple is illustrated in the diagram to the left (Figure H). The thermocouple consists of two pieces of different metals joined together at one end. That end is heated, and an EMF appears at the open end of the loop. To increase the EMF, the thermocouple may be expanded into a thermopile which consists of several pieces of the dissimilar metals joined together and forming a large loop. Alternate

Fig H



The deflection of the meter's needle from zero indicates the presence of a current.

junctions are heated, and the EMF appears across the ends of the large loop. Thermocouple devices are used in a number of applications, such as furnace controls and heat-sensitive instruments.

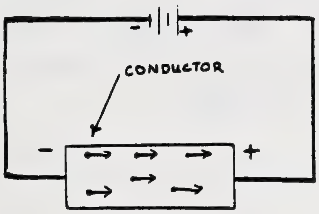
Photovoltaic sources of EMF are used to convert light energy to electrical energy. Often, such sources are called photocells or solar cells, and are made of special semiconductor materials, such as selenium. Such cells are used in satellite power systems, for operating small electronic devices (some "light-powered" watches and radio receivers have been made available) and for use in cameras in order to control exposure of film.

DO EXERCISE 1 NOW (pages 20 to 22).

Current, Resistance, Potential Difference, and Voltage

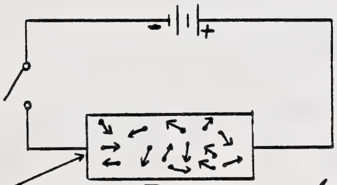
So far in this lesson we have discussed the transfer of electrical energy through the use of a source of EMF, but we have not dealt with some of the details of how that energy is transferred. As you may know, electrical energy transfer in circuits usually occurs through charge motion in the form of current. When an EMF is applied to the ends a conductor, charged particles tend to move inside the conductor in a particular direction. As illustrated by the diagram, the tendency is for the electrons to move from the more negative end toward the more positive end of the conductor. It is the polarity of the source of EMF which determines which end of the conductor is negative, and which end is positive.

Fig I

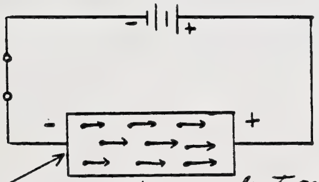


The arrows represent the direction in which free electrons tend to move.

Fig J



Random motion of free electrons



most of the free electrons tend to drift in one direction

Within the conductor, when it is not attached to the source of EMF, electrons may escape from atoms, and move in various directions until captured by other atoms. In a conductor such as copper at normal room temperature (20°C) many electrons may be moving between atoms at a particular time; such electrons are called free electrons. When the source of EMF is attached to the conductor, the free electrons are put under the influence of an electric field due to the applied EMF. This results in free electrons having a tendency to move in a particular direction, rather than randomly (random motion means motion in any direction, with no net motion in one particular direction), as they did when no EMF was applied.

The energy of the source of EMF is used to do work through moving the electric charges (free electrons) through the conductor. The motion of the free electrons in a particular direction is not current; rather, current is the rate of motion of charge. If a charge of one coulomb moves by a point in one second, the current is said to be one ampere. This is shown in symbols below.

$$1A = \frac{1C}{1s}$$

where 1A = one ampere
1C = one coulomb
1s = one second

Current may be classified into two major kinds: direct current (DC) and alternating current (AC). The type of current depends upon the type of source of EMF being used. A DC EMF source maintains a constant polarity for each of its terminals.

Fig K

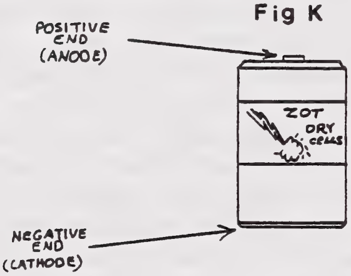
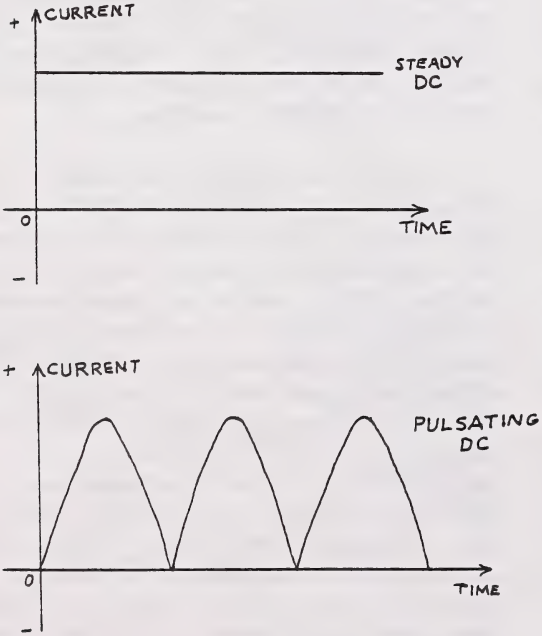
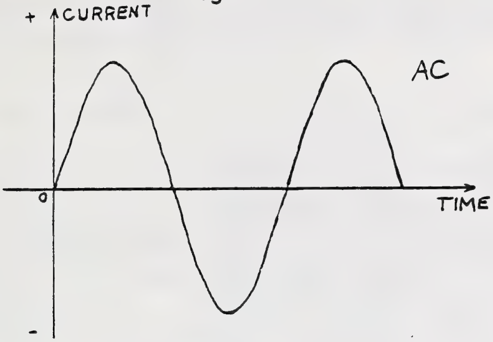


Fig L



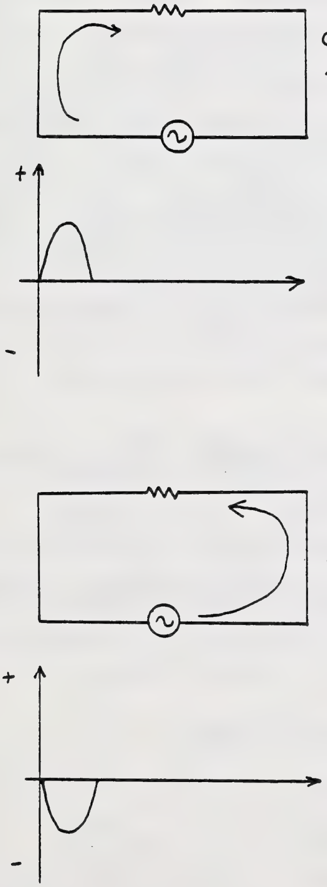
DC can be represented graphically as shown in the Figure L. Note that the line representing DC always remains above or below the horizontal axis. This means that it always flows in one directic Note also that the last diagram shows pulsating DC. This shows that DC can vary in size, but as long as it does not change direction of flow, it is still considered to be DC.

Fig M



The other type of current, alternating current, or AC, has the feature that it changes its direction regularly over a period of time. Usually, AC is produced by generators, which may vary greatly in size and output, from the large generators used to produce the AC used in homes, offices, factories, and other buildings, to the smaller generators (called alternators) used in some cars and trucks. When operating, such sources of EMF produce regular reversals of polarity at their terminals: for a short period of time, one terminal is positive and the other is negative; then, they are reversed in polarity, with the first terminal becoming negative, and the second becoming positive.

Fig N



Current flows in one direction

Current flows in the opposite direction.

When an AC generator is attached to a conductor, and is made to operate, the periodic reversals of polarity result in current direction changing also. This is illustrated in Figure N. Notice that the line representing current appears above and below the horizontal line on alternate half-cycles. This means that the current changes its direction of flow in a regular, "alternating" way. For the positive half-cycle, current flows in one direction. For the next negative half-cycle, current reverses and flows in the opposite direction.

Over a period of time the changing current (AC) can be represented graphically as a series of positive and negative pulses, as shown in Fig. M.

In the remainder of this elective we will be concerned with DC circuits most of the time. Another elective deals with the major features of AC circuits.

Resistance

When an EMF is applied to a condutor, there is usually some opposition to current. One form of this opposition is called resistance. The presence of resistance in a material can be explained using a model which allows us to think of free electrons as being similar to small particles which are accelerated by the electric field which is applied by the source of EMF. The conductor atoms are considered to be particles larger than the electrons and arranged in a regular manner (forming a crystal lattice). The atoms vibrate about fixed positions in the crystal lattice, and their average rate of vibration depends upon the absolute temperature of the conductor. Hence, at room temperature, the atoms will have a particular energy of vibration, on the average. As the free electrons move through the conductor, many of them collide with the atoms, and may bounce off the atoms. In the collisions, the electrons lose energy to the atoms, which tend to increase their energies of vibration. This energy appears as a heating-up of the conductor. Hence, the energy provided by the energy source is lost as heat, and the energy source must continually provide EMF if current flow is to continue. Effectively, there is an opposition to the flow of the electrons due to this energy loss (actually, an energy conversion from electrical energy to heat), and this opposition is called resistance. Resistance is measured in a unit called the ohm (after Georg Simon Ohm, 1787 - 1854).

Factors Affecting Resistance

For a conductor such as a wire, the resistance depends upon several factors, outlined below.

(1) Resistivity - Resistivity is a measurement of the resistance of a piece of a particular kind of material having certain dimensions, and is expressed in ohm-metres, symbolized Ω - m. Some values for the resistivities of some materials at 20°C are given below.

Material	Resistivity (Ω- m)
Aluminium	2.8×10^{-8}
Copper	1.69×10^{-8}
Carbon	3.5×10^{-5}
Iron	1.0×10^{-7}
Nickel	7.8×10^{-8}
Silver	1.6×10^{-8}
Steel	1.8×10^{-7}

Note that next to silver, copper has the lowest value of resistivity. The lower the value of resistivity, the better is a material when used as a conductor.

(2) Length - The greater the length of a piece of conductor, the greater the resistance of that piece of conductor. For example, if you had two pieces of copper wire of a particular size at the same temperature, one having a length of 10 m and the other having a length of 1.0 m, the longer piece would have more resistance. This may be understood if we consider what happens when the same EMF is applied to each piece of wire. Suppose that 10V is applied to the two pieces of wire mentioned above.

10 m wire

$$\frac{\text{Voltage}}{\text{Unit length}} = \frac{10\text{V}}{10\text{m}} = \frac{1.0\text{V}}{\text{m}}$$

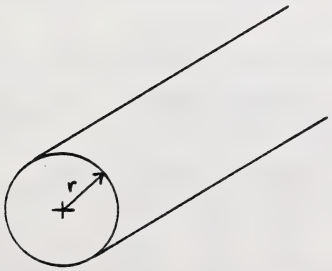
1.0 m wire

$$\frac{\text{Voltage}}{\text{Unit length}} = \frac{10\text{V}}{1.0\text{ m}} = \frac{10\text{V}}{\text{m}}$$

The calculation above illustrates that the shorter wire has a greater voltage per unit length. This means that the free electrons in 1.0 m of the shorter wire will be given more energy on the average than the free electrons in 1.0 m of the longer wire.

This will tend to produce a greater rate of flow (current) in the shorter wire than in the longer wire for the same applied EMF. Another way of saying this is to state that the resistance is lower in the shorter piece of wire.

(3) Cross-sectional Area - The cross-sectional area of a uniform piece of conductor is the area of an end of the conductor. For a wire, the cross-section usually is circular. Hence, cross-section area would be calculated using



$$A = \pi r^2$$

where A = circular cross-sectional area
r = radius
π = a constant approximately equal to 3.14.

The greater the cross-sectional area, the lower is the resistance, other factors being constant. For example, suppose that you have two pieces of copper wire having the same length and temperature, but one piece is thicker than the other. The thicker wire will have less resistance.

We can understand this by considering what happens when the same EMF is applied to two pieces of copper wire of the same length and temperature but with one having half of the cross-sectional area of the other. The thicker piece of wire will have double the volume of the thinner piece and consequently will have double the amount of copper in it. This also means that for equal lengths, the thicker piece of wire will have twice as many free electrons available. Thus, when equal EMF's are applied to the two pieces of wire, twice as many free electrons will flow in the thicker piece effectively resulting in less resistance in the thicker piece of wire.

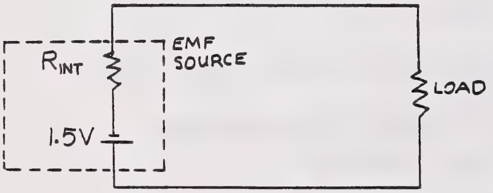
(4) Temperature - Generally, for conductors, as temperature increases, resistance increases. This is not true for all materials. For example, for materials known as semi-conductors, as temperature increases, resistance decreases.

With conductors, as temperature increases, the vibrations of the atoms tend to increase. This makes the space that they occupy somewhat larger, on the average, increasing their chances for collisions with electrons. This means that electrons will hit atoms more often, and this will result in increased resistance.

EMF, Internal Resistance and Potential Drop

When an EMF is applied to the ends of a conductor there will be a voltage across the conductor. Normally, the voltage across the conductor will not be equal to the EMF of the source. The reason for this is that when a load on a source of EMF acts as an energy drain on that source, the source cannot maintain the EMF at the no-load level. This sometimes is shown for dry cells by including an internal resistance with the EMF source as shown in the following diagram.

Fig O



The EMF source is shown enclosed in the dashed lines. R_{in}. stands for the internal resistance. When the source of EMF is not connected to a load, so that it is providing no energy for current flow, there will be no current flow throu R_{INT}, and there will be no loss of energy. Thus, with no load, the source of EMF is 1.5 V.

However, when a load is connected there will be a closed path for current to flow through, and this means that the EMF source provides energy. Some of this energy will be applied to R_{INT}, as well as to the load, and therefore the load will not have the whole 1.5 V applied to it. The voltage across the load is known as the potential drop or the voltage drop. The potential drop across the load equals the source EMF minus the voltage drop across the internal resistance. Hence,

$$PD_{LOAD} = EMF - PD_{R_{INT}}$$

where PD_{LOAD} = potential drop across the load

EMF = no-load EMF of the source

$PD_{R_{INT}}$ = potential drop across the internal resistance

To avoid confusion in the use of the terms EMF, potential drop and voltage drop, it should be remembered that the term EMF refers to the energy per unit charge that a source of EMF can provide under the condition of there being no load. Potential drop and voltage drop refer to the voltage across a load or a resistance when a source of EMF is applied. In general, only a source of EMF can provide an EMF; an EMF does not appear across a load or a resistance.

DO EXERCISE 2 NOW (pages 23 to 27).

Ohm's Law

Ohm's law gives the relationship between voltage and current in a load such as a resistance. In symbols, Ohm's law is

$$I = \frac{V}{R}$$

where I = current in A
V = voltage drop in V
R = resistance in Ω

In words, Ohm's law may be stated as follows:

> The current through a resistance varies directly with the voltage, and inversely with the resistance.

This law gives us a way of calculating quantities such as current, voltage, and resistance if we know the values of two of the quantities. Some examples of the use of Ohm's law appear on the next two pages.

Examples

1. What current flows through a resistor of $2.5 \times 10^2 \Omega$ when a voltage of 12.0 V is applied to it?

Given: $R = 2.5 \times 10^2 \Omega$

$V = 12.0\ V$

Unknown: I

Solution: $I = \frac{V}{R}$

$I = \frac{12.0\ V}{2.5 \times 10^2 \Omega} = 0.048\ A$

$I = 4.8 \times 10^{-2}\ A$

The current through the resistor is 4.8×10^{-2} A.

2. Find the voltage drop across a resistor of 15Ω when 6.0A flows through it.

Given: $R = 15 \Omega$

$I = 6.0\ A$

Unknown: V

Solution: $I = \frac{V}{R}$

$V = IR$

$V = 6.0\ A \times 15 \Omega$

$V = 90\ V$

The voltage drop is 90 V.

3. A battery rated with an EMF of 4.50 V is used to produce a current of 2.00×10^{-1} A through a resistor of 20.0Ω. Calculate the value of the internal resistance of the battery.

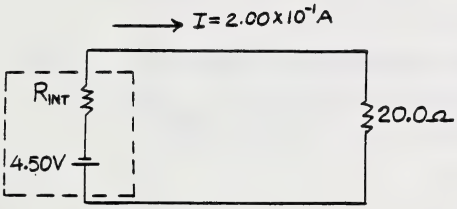
Given:

Battery EMF = 4.50 V
Load = 20.0Ω
I = 2.00×10^{-1} A

Unknown:

Internal resistance of the battery, R_{INT}.

Method:



Since $PD_{LOAD} = EMF - PD_{R_{INT}}$,

$$PD_{R_{INT}} = EMF - PD_{LOAD}.$$

$$PD_{LOAD} = V_{LOAD} = I_{LOAD} \times R_{LOAD}$$

$$= 2.00 \times 10^{-1}\ A \times 20.0\ \Omega$$

$$= 4.00\ V$$

$$PD_{R_{INT}} = 4.50\ V - 4.00\ V$$

$$= 0.50\ V$$

The same current that flowed through the load would have flowed through R_{INT}.

$$I = \frac{PD_{R_{INT}}}{R_{INT}}$$

$$R_{INT} = \frac{PD_{R_{INT}}}{I}$$

$$= \frac{0.50\ V}{2.00 \times 10^{-1}\ A}$$

$$= 2.5\ \Omega$$

The internal resistance of the battery is 2.5Ω.

Electrical Energy and Power

A source of EMF is rated in volts, which is a measure of the energy per unit charge that might be made available by the source (under ideal conditions). To move charge through a material, the source of EMF must provide energy, or do work. The energy or work is given by.

$$E = Vq$$

where E = energy or work in J
V = voltage in V
q = charge in C

This formula indicates that for a particular amount of charge, q, to be moved through a particular voltage drop, V, work or energy, E, must be provided. The rate of flow of charge is current, and current may be expressed as

$$I = \frac{q}{t}$$

where I = current in A
q = charge in C
t = time in s.

Hence, $q = It$

and $E = Vq = V(It)$

$E = VIt$ where E = energy in J
V = voltage in V
I = current in A
t = time in s

This formula may be used to calculate the amount of energy provided by a source of EMF when current flows for a particular period of time. Some examples of the use of the formula appear below.

Examples

1. How much electrical energy is provided by a 12.0 V battery when it is used to operate a motor which carries a current of 25 A for 30 s? (Assume that 12.0 V is the voltage applied to the motor while the current flows.)

Given: $V = 12.0\ \text{V}$
$I = 25\text{A}$
$t = 30\ \text{s}$

Unknown: E

Method: $E = VIt$

$E = 12.0\ \text{V} \times 25\ \text{A} \times 30\ \text{s}$

$E = 9.0 \times 10^{3}\ \text{J}$

The electrical energy provided by the battery is 9.0×10^{3} J.

2. An electrical appliance which carries 10.0 A at 1.20×10^{2} V must provide 3.60×10^{5} J of heat. Assuming that the appliance can convert the electrical energy to heat with 100% efficiency, calcualte how long the appliance must operate to provide this energy.

Given: $V = 1.20 \times 10^{2}\text{V}$

$I = 10.0\ \text{V}$

$E = 3.60 \times 10^{5}\ \text{J}$

Unknown: t

Method: $E = VIt$

$$t = \frac{E}{VI}$$

$$t = \frac{3.60 \times 10^{5}\ \text{J}}{1.20 \times 10^{2}\text{V} \times 10.0\ \text{A}}$$

$$= 3.00 \times 10^{2}\ \text{s}$$

The time required in 3.00×10^{2} s.

As you should know from previous studies in physics, power is defined as the rate of energy production or consumption. In a closed electrical circuit, electrical energy is being produced by the energy source, which is converting some other form of energy (chemical, mechanical, radiant, for example) to electrical energy. Electrical energy is being consumed by the load, and if this load is a resistance, this "consumption" takes the form of conversion of electical energy to heat. This conversion of electrical energy to heat in a resistance is sometimes known as joule heating, after J. P. Joule who was one of the men who observed this phenomenon.

In an electrical circuit it is not only the heating of a resistance which is important, but also the rate of heating. The rate of heating is a measure of the electrical power involved in the circuit. Since power is defined as the rate of energy production or consumption we can express it in formula form as shown on p. 18.

$$P = \frac{E}{t}$$

where P = power in W (watts)
E = energy in J
t = time interval in s

Since $E = VIt$ in electrical circuits,

we have $P = \frac{E}{t} = \frac{VIT}{t}$

and $P = VI$

where P = power in W
V = voltage in V
I = current in A

The above expression indicates that electrical power is dependent upon the work or energy per unit charge and the rate of movement of charge.

By the use of Ohm's law, the formula for power can be put into two other forms which include resistance. These forms are shown below.

$P = VI$
Since $V = IR$,
$P = (IR)(I)$
$P = I^2R$

$P - VI$
Since $I = \frac{V}{R}$,
$P = (V)\,\frac{V}{R}$
$P = \frac{V^2}{R}$

where P = power in W
I = current in A
V = voltage in V
R = resistance in Ω

The formula $P = I^2R$ shows that power depends upon the square of the current for a particular resistance. Hence, if the current through a constant resistance is doubled, the power will be increased by a factor of four. For the resistance, this means that the rate at which heat is being produced is increased four times. Unless the circuit component has been designed to handle such an increase in the rate of heating, it may be damaged. Some components may be rated as to their maximum power handling capabilities. For example, resistors may have ratings of 0.25 W, 0.5 W, 1 W, 2 W, 5 W, 10 W, 20 W, and so on. When selecting a resistor for use in a circuit, the maximum likely power handling requirements should be calculated in order to decide the proper rating for the resistor.

DO EXERCISE 3 NOW (pages 27 to 30).

Lesson Summary

1. An electrical circuit involves an electrical energy source, a path that can be closed to allow electrical energy to flow, and a load.

2. There are several types of sources of EMF, including chemical, mechanical, piezoeletric, themoelectric and photovoltaic sources.

3. EMF, or electromotive force, is a measure of energy per unit charge provided by a source of EMF, and specified in volts (V).

$$1V = \frac{1J}{1C}$$

4. Current is a measure of the rate of motion of charge, and is expressed in amperes (A).

$$1A = \frac{1C}{1s}$$

In conductors, the existence of free electrons results in current when an EMF is applied.

5. DC flows in one direction. AC changes its direction of flow regularly.

6. Resistance is the opposition to current flow in a material.

7. The resistance of a piece of material such as wire depends upon the following factors.

   (1) Resistivity of the material
   (2) Length of the piece of material
   (3) Cross-sectional area of the piece of material
   (4) Temperature of the piece of material

8. When a source of EMF is applied to a load, the rated EMF often is larger than the voltage across the load. This may be explained in terms of the internal resistance of the source of EMF.

9. Ohm's law: $I = \frac{V}{R}$, $V = IR$, $R = \frac{V}{I}$

10. Electrical energy: $E = Vq, = VIt$

11. Electrical power: $P = VI = \frac{V^2}{R} = I^2R$

EXERCISES

Exercise 1

1. Name three essential features of electrical circuits.

(a) ______________________________

____

____

(b) ______________________________

____

____

(c) ______________________________

____

____

2. Draw a diagram showing a DC source and a resistor in an electrical circuit.

3. What happens if an electrical circuit is opened?

____

____

____

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4. Draw circuit symbols for the following:

   (a) AC source

   (b) Open switch

   (c) Ground

   (d) Coil

   (e) Capacitor

5. What does EMF stand for?

   ____

6. Calculate the EMF required to provide 60.0 J in moving a charge of 3.0 C.

7. Match the types of EMF sources with the descriptions.

chemical ______

mechanical ______

piezoelectric ______

thermoelectric ______

photovoltaic ______

(a) light incident of a p-n junction of a semi-conductor produces a separation of charges.

(b) Relative motion between a conductor and a magnetic field produces an EMF.

(c) An EMF is produced by electrical cells with electrodes and an electrolyte.

(d) Heat applied to one junction of two dissimilar metals produces EMF.

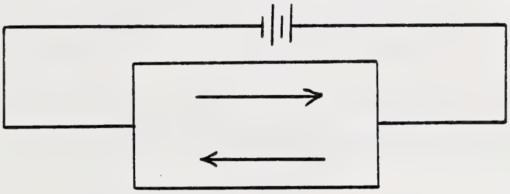
(e) Pressure on crystals produces a momentary separation of charges.

Exercise 2

1. What is electrical current?

2. (a) What are free electrons?

   (b) In the following diagram, a DC source is shown connected to a piece of conductor. One of the arrows represents the direction of the electric field (E) and one represents the direction of current (I). Label the one representing the direction of the electric field with E, and the one representing the direction of current with I.



   (c) Explain why the two arrows in part (b) above are in opposite directions.

   The electric field direction is the direction in which a positive charge tends to move in the field. The current is due to the flow of electrons, which are negative particles.

3. (a) What is the difference between AC and DC?

____

____

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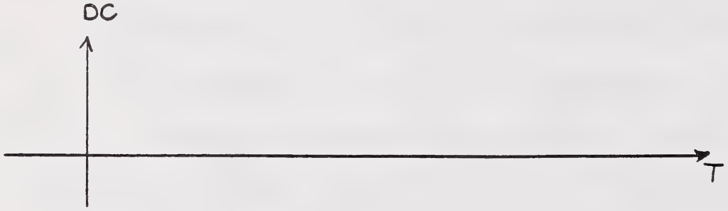
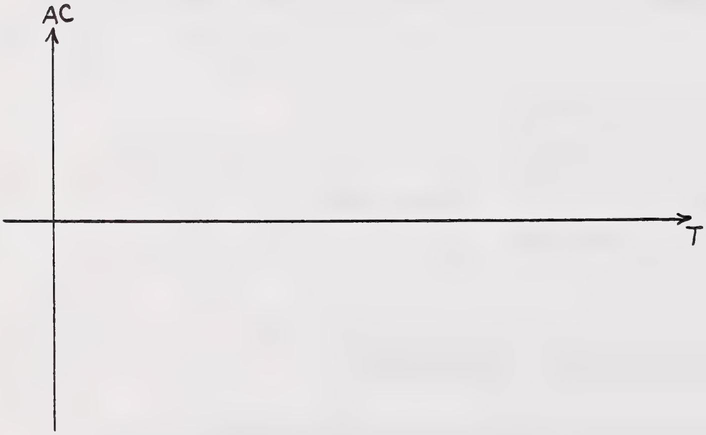
(b) Using the following sets of axes, draw lines illustrating DC and AC.





4. (a) What is electrical resistance?

____

____

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(b) Explain resistance in terms of what happens when a source of EMF is applied to a conductor, and electron flow occurs.

____

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5. Name the four factors upon which the resistance of a conductor, such as wire, depend.

(a) ____

(b) ____

(c) ____

(d) ____

6. Two pieces of copper wire, each 1.0 m long, with circular cross-sections, and at 20 °C, have different diameters. One piece, with a resistance R_1, has a diameter that is three times the diameter of the other piece which has a resistance R_2. Find the value of the ratio

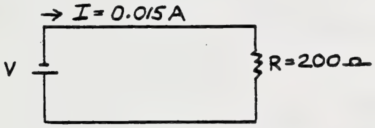
   $\frac{R_1}{R_2}$.

7. Explain why the rated EMF of a DC source is more than the voltage across the load in a closed circuit.

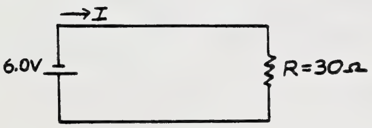
Exercise 3

1. Use Ohm's law to calculate the unknown quantities shown in each of the following diagrams. Assume that the internal resistances of the DC sources are zero.

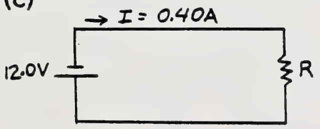
(a) V is unknown.



(b) I is unknown.



(c) R is unknown.



2. (a) If the current is to remain constant, and resistance is doubled, what must happen to the voltage?

____

(b) If the voltage is to remain constant, and the resistance is doubled, what must happen to the current?

____

3. (a) A battery having an internal resistance of $5.00 \times 10^{-1}\,\Omega$ is connected to an external resistor of $12.00\,\Omega$. If a current of 3.60×10^{-1} A results in the circuit, what is the EMF of the battery?

(b) The conditions described in part (a) last for 10.0 min.

(i) What is the time in seconds? __________

(ii) What is the voltage drop across only the internal resistance? __________

(iii) What is the total energy used by the internal resistance? __________

4. A heater is rated at 1.20×10^3 W when 1.20×10^2 V is applied to it and it is at full operating temperature.

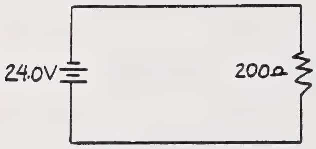
   (a) What current would the heater draw when operating?

   (b) What resistance would the heater element have when it is operating?

   (c) If the heater operated for 1.00 h, how much heat would it produce?

   (d) If the heater operated for 1.00 h, how much charge would move through the element?

5. The following diagram shows a resistor in a circuit connected to a DC source. If the resistor has a power rating of 2.0 W, is it possible that it could be damaged?



Show calculations to support your answer.

END OF LESSON 1A

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(2) All exercises are completed. If not, explain why.
(3) Your work has been re-read to ensure accuracy in spelling and lesson details.
(4) The Lesson Record Form is filled out and the correct lesson label is attached.
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3. POSTAGE RATES

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Take your lesson to the Post Office and have it weighed. Attach sufficient postage and a **green first-class sticker to the front of the envelope, and seal the envelope. Correspondence lessons will travel faster if first-class postage is used.**

Try to mail each lesson as soon as it has been completed.

When you register for correspondence courses, you are expected to send lessons for correction regularly. Avoid sending more than two or three lessons in one subject at the same time.

REFLECTION FROM CURVED SURFACES

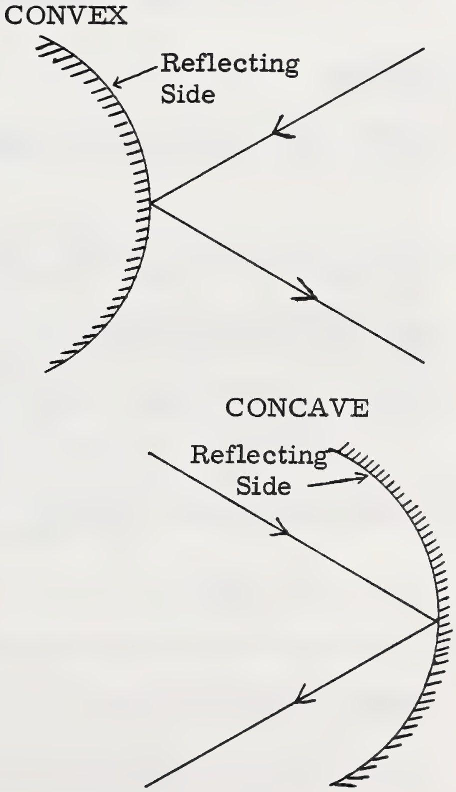
Laws of Reflection

If you have ever been in the "fun house" at an amusement park, you have probably seen your image greatly distorted in a curved mirror. You see similar distortions in reflections in the bowl of a shiny spoon or the polished surface of an automobile. The images look peculiar because of the irregular curvature of the surface, but they are formed by light rays which are behaving according to the laws of reflection you learned earlier.

We can get some understanding of reflection from curved surfaces by considering the reflection of light from curved mirrors. A curved mirror may be considered as a section of a hollow sphere. If the inside of the sphere is polished to reflect light, the resulting mirror is called a concave mirror and if the outside of the sphere is polished to reflect light, the resulting mirror is called a convex mirror.

In your kit there are two curved mirrors, stuck together. By examining each of the mirrors visually, you should be able to see that one curves outward, and one curves inward. To help in seeing this, place the edge of a ruler across the diameter of each mirror. The mirror that curves outward is called a convex mirror. The one that curves inward is called a concave mirror. See Fig. A. One way to help in remembering the difference between convex and concave is to remember that "concave" has the word "cave" in it, and a concave mirror curves inward, like a cave.

Fig. A



The ways in which the convex and concave mirrors affect light are quite different. Concave mirrors make parallel light rays converge on each other and are therefore also called converging mirrors. Convex mirrors make parallel light rays diverge and therefore are also called diverging mirrors.

The centre of a curved reflecting surface is called the centre of curvature (C). Any straight line drawn from the centre of curvature to the curved surface is called the radius of curvature. The geometric centre of a curved mirror is called the vertex (V). The straight line passing through V and C is called the principal axis. If a group of rays parallel to the principal axis strikes a concave mirror, the rays all reflect to the same point on the principal axis, called the principal focus (F). See Fig. C. The distance along the principal axis between the principal focus and the vertex is called the focal length (f). The principal focus is half way between the vertex and centre of curvature. By measuring the distance VF, Fig. C, you can see that the focal length is one half the radius of the mirror, that is $f = \frac{r}{2}$. This is not precisely true, but it is very nearly so if the size of the mirror is small compared with the radius of the curvature.

Fig. B

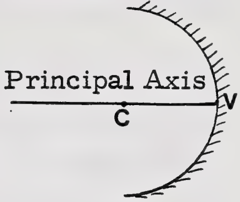
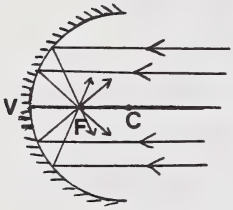


Fig. C



QUESTIONS

1. Why do you see distorted images in a fun house?

2. What is a curved mirror?

3. What is a concave mirror?

4. What is a convex mirror?

5. Draw a diagram showing a spherical mirror and label the convex and concave surfaces, the principal axis, principal focus, centre of curvature and focal length.

6. What is the relationship between the focal length and the radius of curvature of a concave mirror?

____

7. Under what conditions is the above relationship true?

____

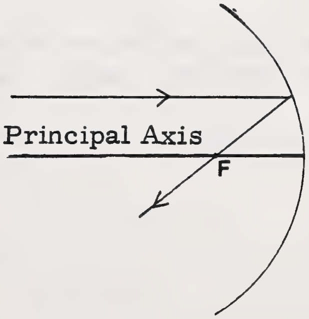
____

Geometrical location of the images

To determine the position of an image in a concave mirror it is necessary to use only two rays that intersect. But which two rays? In a concave mirror, any ray parallel to the principal axis is reflected through the principal focus (F). Conversely, any ray through F is reflected parallel to the principal axis. Another ray we can use is the one that goes through the centre of curvature (C) from the tip of the object. Since it moves along a radius of curvature, it hits the mirror with an angle of incidence of 0°. The reflected ray goes back along the same path as the incident ray, since the angle of reflection is 0°. To locate the image in a converging mirror, then, we may use any two of the rays mentioned below.

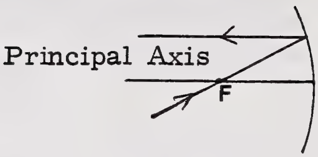
1. A ray that is parallel to the principal axis and is reflected through the principal focus, Fig. D.

Fig. D



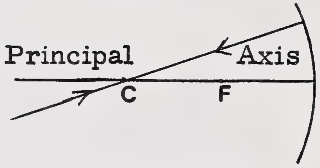
2. A ray that passes through the principal focus and is reflected parallel to the principal axis, Fig. E.

Fig. E



3. A ray that passes through the centre of curvature and is reflected back along the same path, Fig. F.

Fig. F



Besides choosing two rays out of the three mentioned above, you have to go through the following seven steps for the location of the image in a concave mirror.

Steps in image location by construction:

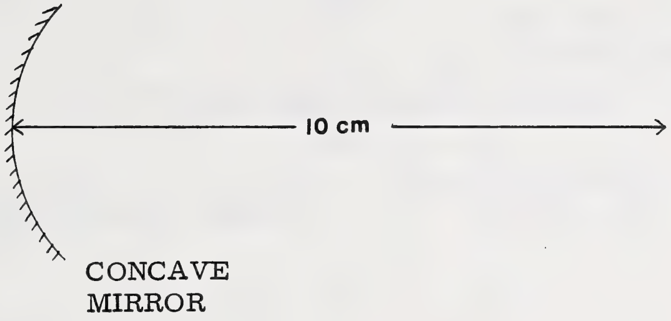
1. Choose a suitable scale for your drawing. (e.g. Let 1 cm represent 4 cm)
2. Represent the curved mirror by the arc of a circle, drawn to scale.
3. Mark the centre of curvature, C, on the principal axis.
4. Mark the principal focus, F, one half the distance from the mirror to C.
5. On the principal axis, and at right angles to it, draw an arrow to represent the object at the given distance from the mirror.
6. Locate the top of the image by drawing two rays.
   (a) From the top of the object draw a line, parallel to the principal axis, to the mirror and reflected back through F.
   (b) Draw a ray from C to the top of the object and extend it to meet the line in (a).
7. From this point draw a perpendicular to the principal axis. This line represents the image. Label it.

We will take a sample construction using these steps.

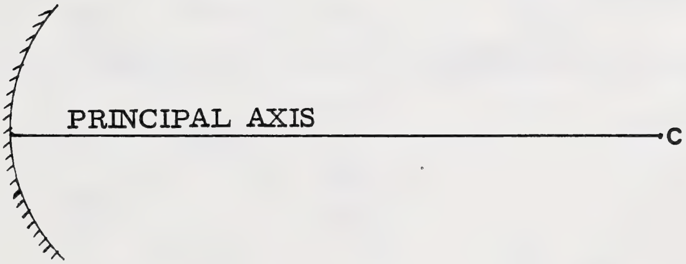
Example: Sketch a scale diagram for the location of the image of an object placed 60 cm in front of a concave mirror of radius of curvature 50 cm.

Step 1 Let 1 cm represent 5 cm.

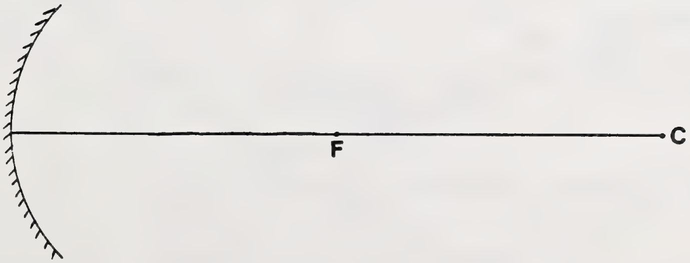
Step 2



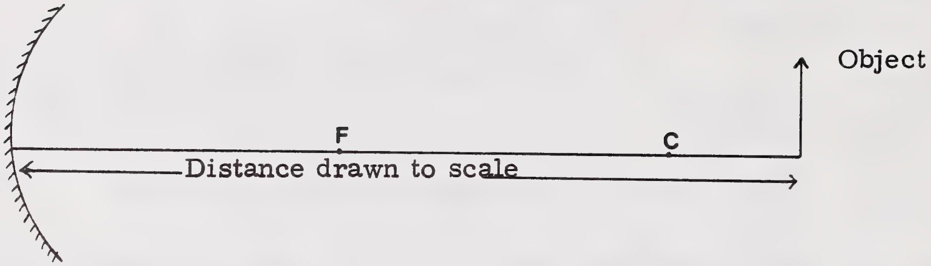
Step 3



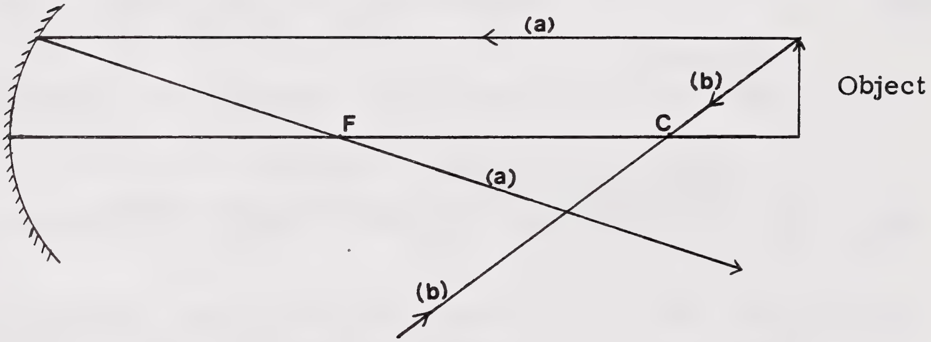
Step 4



Step 5



Step 6



Step 7

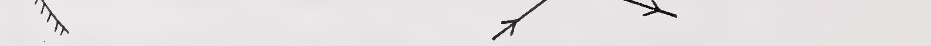
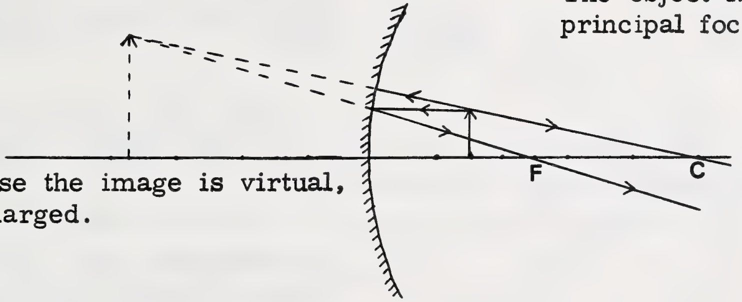


Fig. G to Fig. L show the formation of the image after reflection from a concave mirror. Study these figures very carefully. Later you will compare these predicted images and their characteristics with the actual observations made in Experiment #3.

These diagrams show the images formed by a concave mirror. The focal length of this mirror is 5 cm (r = 10 cm). Scale 1 cm = 2 cm

Fig. G

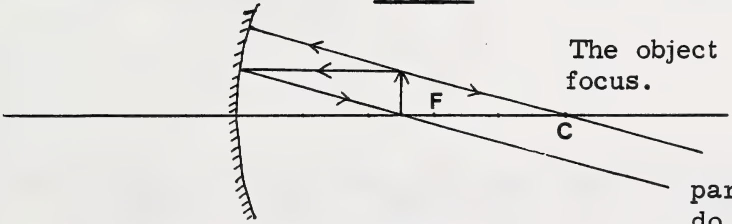
The object is between the principal focus and the mirror.



In this case the image is virtual, erect, enlarged.

Fig. H

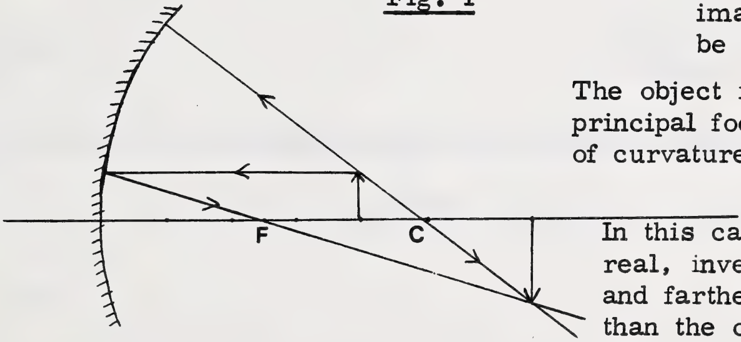
The object is at the principal focus.



In this case the reflected rays are parallel and therefore do not intersect. The image can be said to be at infinity.

Fig. I

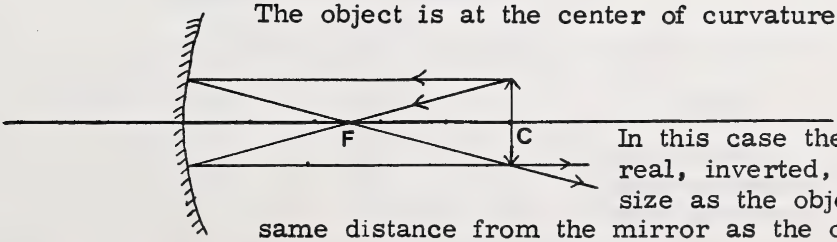
The object is between the principal focus and the center of curvature.



In this case the image is real, inverted, enlarged, and farther from the mirror than the object.

Fig. J

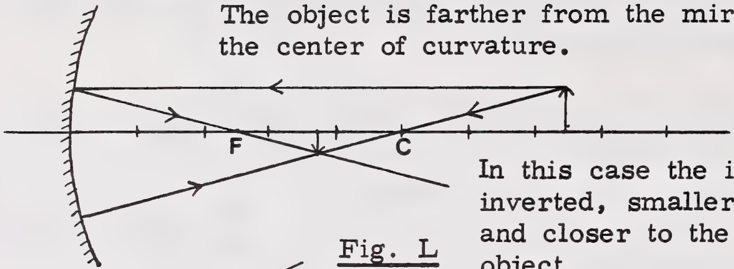
The object is at the center of curvature.



In this case the image is real, inverted, the same size as the object, and the same distance from the mirror as the object.

Fig. K

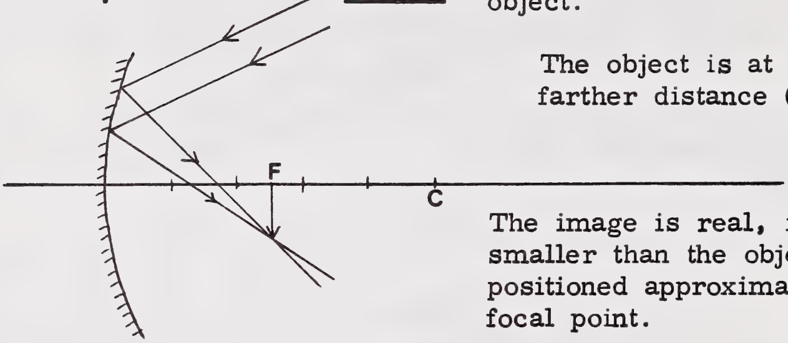
The object is farther from the mirror than the center of curvature.



In this case the image is real, inverted, smaller than the object, and closer to the mirror than the object.

Fig. L

The object is at a much farther distance (say infinity)

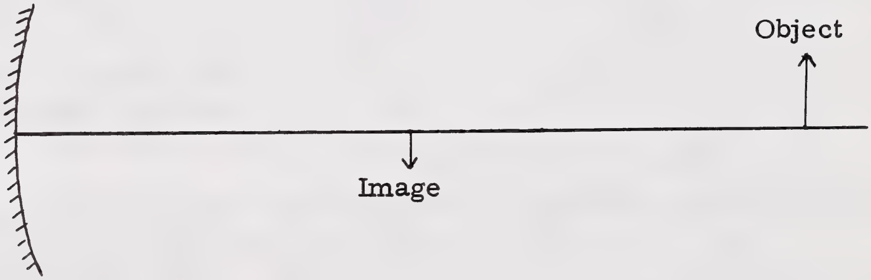


The image is real, inverted, smaller than the object and positioned approximately at the focal point.

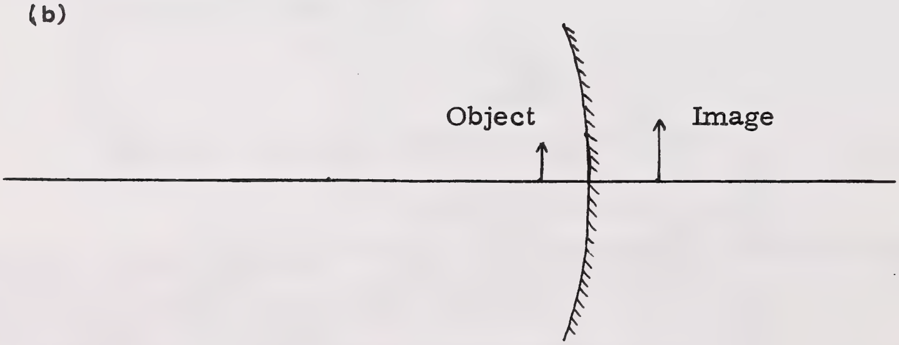
QUESTIONS

1. An object and its image appear as shown below. Locate the centre of curvature of the mirror in each case, using ray diagrams.

(a)

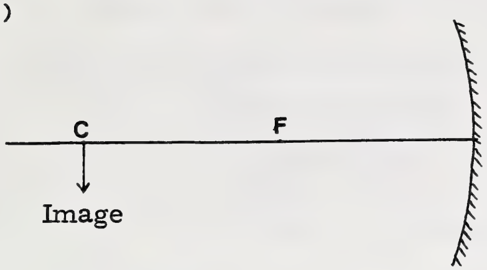


(b)

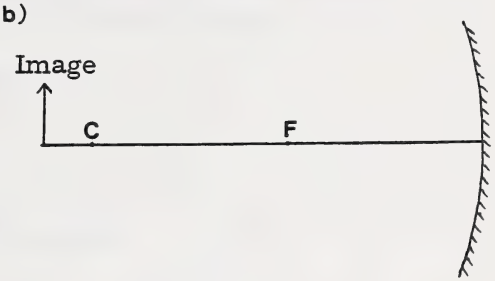


2. On each of these diagrams the images formed by concave mirrors are shown. Using ray diagrams locate the objects.

(a)



(b)



3. A candle is placed 30 cm from a concave mirror with a focal length of 20 cm. By means of a scale diagram locate the image and state its characteristics.

Scale: _______ represents _______

Image:

Real/Virtual _____________
Smaller/Larger ___________
Erect/Inverted ___________

4. Using a careful scale drawing locate the image in each of the following cases.

(a) Concave mirror with a radius of curvature of 40 cm. Object 10 cm in front.

Scale:

Image:

Real/Virtual _____________
Smaller/Larger ___________
Erect/Inverted ___________

4. (b) Concave mirror with radius of 40 cm; object 40 cm in front.

Scale:

Image:

Real/Virtual ____________

Smaller/Larger __________

Erect/Inverted ___________

(c) Concave mirror with radius of 60 cm and object 80 cm in front of it.

Scale:

Image:

Real/Virtual ____________

Smaller/Larger __________

Erect/Inverted ___________

(d) Concave mirror with radius of 60 cm and object at a distance of 30 cm in front of it.

Scale:

Image:

Real/Virtual ____________

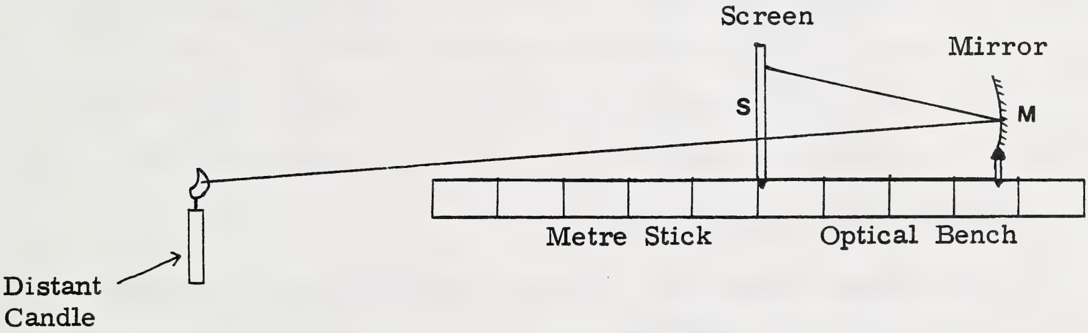
Smaller/Larger __________

Erect/Inverted ___________

EXPERIMENT #3 Reflection from a concave mirror

AIM: To study the formation of images in a concave mirror and determine the characteristics of the images formed.

APPARATUS:
- Metre stick and supports
- Concave mirror
- Mirror support
- Screen support
- Candle
- 15 cm × 15 cm card as screen



PROCEDURE:

Step 1

Assemble the optical bench as shown in the diagram. Have another person hold the candle above and to one side of the screen several metres away from it. Move the screen S back and forth until you get an image of the candle flame on the screen which is clearly defined, or sharp. Measure the distance SM and record it on your Data Sheet. This is the focal length f.

Step 2

Repeat the investigation with the candle at a distance 2f or C from the mirror, then between C and F, then inside F, and finally at F. Complete the chart in the OBSERVATIONS.

OBSERVATIONS:

Distance of screen from vertex of concave mirror ______ cm

Focal length of concave mirror is ______ cm

Observation Number	Position of Object	Position of Image	Characteristics of Image		
			Size	Attitude	Kind
1	Beyond 2f	Between C and F	Smaller	Inverted	Real
2	At 2f				
3	Between C and F				
4	Inside F				
5	At F				

ANALYSIS AND CONCLUSION:

1. The image formed by a concave mirror is real and inverted if the distance of the object is ______________________.
2. The image formed by a concave mirror is virtual and erect if the distance of the object is ______________________.
3. Size of the image formed may vary depending on ______________

Lesson Summary

- A curved mirror may be considered as a section of a hollow sphere.
- The mirror that curves outward is called a convex mirror.
- The mirror that curves inward is called a concave mirror.
- The image formed by a concave mirror can be real or virtual, inverted or erect and may be smaller or larger than the object.
- The image formed by a convex mirror is always virtual, erect and smaller than the object.

CONGRATULATIONS! You have completed Lesson 2C. Please check to make sure all questions are completed and no careless errors have been made. Then submit the lesson immediately for correction, rather than saving up several lessons before mailing.

End of Lesson 2C

LESSON RECORD FORM

3260 PHYSICS 30
Elective C
Revised 88/11

FOR STUDENT USE ONLY

Date Lesson Submitted ____________________

Time Spent on Lesson ____________________

(If label is missing
or incorrect)

File Number ____________________

Lesson Number ____________

FOR SCHOOL USE ONLY

Assigned
Teacher: __________

Lesson Grading: ________

Additional Grading
E/R/P Code: ________

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ALBERTA CORRESPONDENCE SCHOOL

MAILING INSTRUCTIONS FOR CORRESPONDENCE LESSONS

1. BEFORE MAILING YOUR LESSONS, PLEASE SEE THAT:

(1) All pages are numbered and in order, and no paper clips or staples are used.
(2) All exercises are completed. If not, explain why.
(3) Your work has been re-read to ensure accuracy in spelling and lesson details.
(4) The Lesson Record Form is filled out and the correct lesson label is attached.
(5) This mailing sheet is placed on the lesson.

2. POSTAGE REGULATIONS

Do **not** enclose letters with lessons.

Send all letters in a separate envelope.

3. POSTAGE RATES

First Class

Take your lesson to the Post Office and have it weighed. Attach sufficient postage and a **green first-class sticker to the front of the envelope, and seal the envelope. Correspondence lessons will travel faster if first-class postage is used.**

Try to mail each lesson as soon as it has been completed.

When you register for correspondence courses, you are expected to send lessons for correction regularly. Avoid sending more than two or three lessons in one subject at the same time.

DIVERGING MIRRORS

Images Formed by Diverging Mirrors

In diverging mirrors, the principal focus (F) and the centre of curvature (C) are virtual, since they are located behind the mirror. For the construction of the image in a convex mirror, we use two rays out of the following three as we did in the case of concave mirrors.

1. A ray that is parallel to the principal axis is reflected as if it had gone through the principal focus. See Fig. A.
2. A ray appearing to pass through the principal focus is reflected parallel to the principal axis. See Fig. B.
3. A ray appearing to pass through the center of curvature is reflected back along the same path. See Fig. C.

Fig. A

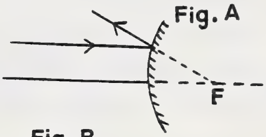


Fig. B

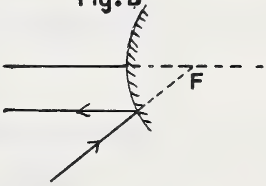
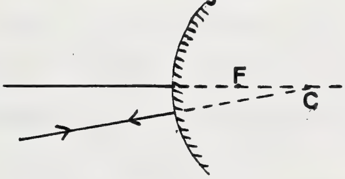
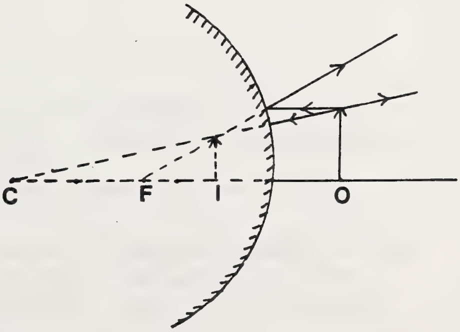


Fig. C



You have to follow the same seven steps for the image location which you learned in Lesson 2C, page 4. If you follow those steps for the case of a convex mirror which has a radius of curvature of 20 cm and object 5 cm in front of it, the image will be behind the mirror as shown in Fig. D. The two reflected rays are diverging and will not actually intersect at a point. But when they are extended behind the mirror, they intersect. Therefore it will appear as if these rays are coming from that point. The image is formed at this point and is a virtual image. It is smaller in size and erect.

Fig. D



EXERCISES

1. Using a careful scale drawing, locate the image in each of the following cases and determine its characteristics.

   (a) Convex mirror with a radius of curvature of 20 cm; object 10 cm in front of it.

   Scale:

   Image:

   Real/Virtual ________
   Smaller/Larger ________
   Erect/Inverted ________

   (b) Convex mirror with a radius of curvature of 20 cm; object 30 cm in front of it.

   Scale:

   Image:

   Real/Virtual ________
   Smaller/Larger ________
   Erect/Inverted ________

2. The image formed by a convex miror (as shown in Fig. D) was virtual, erect and smaller than the object. Did it always have these characteristics?

____

Formula to Locate and Characterize Images

The location of an image formed by a spherical mirror can be found by using this formula:

$$\frac{1}{D_o} + \frac{1}{D_i} = \frac{1}{f} \quad \text{or} \quad f = \frac{D_o \times D_i}{D_o + D_i}$$

where D_o is the distance of the object from the mirror, D_i is the distance of the image from the mirror and f is the focal length of the mirror. The formula is also called the mirror formula and is valid for both, concave and convex mirrors. The following rules must be applied when using this formula.

1. For concave mirrors f is positive and for convex mirrors f is negative.
2. D_o is always positive.
3. If D_i is positive, the image is real, and in front of the mirror; if D_i is negative, the image is virtual and behind the mirror.

When you are making scale diagrams you can always tell by measurement whether the image is larger than the object, smaller or the same size. The magnification produced by a mirror is defined as the relation of the size of the image to the size of the object, or

$$\text{Magnification} = \frac{\text{Size of image } (S_i)}{\text{Size of object } (S_o)}$$

or

$$M = \frac{S_i}{S_o}$$

Also it could be proved mathematically that magnification is related to D_i and D_o by the relation

$$M = \frac{D_i}{D_o}$$

Therefore you can tell whether the image will be smaller, larger or of the same size if you know the values of D_i and D_o. Since in magnification we are interested in the size of the image and the object, when using $M = \frac{D_i}{D_o}$, we do not take into consideration the negative sign of the D_i for virtual images. In other words, magnification will be always a positive quantity. Its value may be less than unity (image smaller than the object), equal to unity (image same size as the object), or greater than unity (image greater than the object).

EXAMPLE 1

An object is placed 30 cm in front of a concave mirror of focal length 20 cm. Find the position of the image and give the characteristics of the image.

Given: $f = +20$ cm (concave mirror f +ve)
$D_o = 30$ cm

To find: D_i

Solution:

$$\frac{1}{D_o} + \frac{1}{D_i} = \frac{1}{f}$$

$$\frac{1}{30} + \frac{1}{D_i} = \frac{1}{20}$$

$$\frac{1}{D_i} = \frac{1}{20} - \frac{1}{30}$$

$$\frac{1}{D_i} = \frac{3 - 2}{60}$$

$$\frac{1}{D_i} = \frac{1}{60}$$

$$D_i = 60 \text{ cm}$$

or

$$f = \frac{D_o \times D_i}{D_o + D_i}$$

$$20 = \frac{30D_i}{30 + D_i}$$

$$30D_i = 20(30 + D_i)$$

$$30D_i = 600 + 20D_i$$

$$30D_i - 20D_i = 600$$

$$10D_i = 600$$

$$D_i = \frac{600}{10} = 60 \text{ cm}$$

The image is real (D_i is +ve), larger ($\frac{D_i}{D_o}$ greater than unity) and inverted (because image is real).

EXAMPLE 2

An object is placed 3.0 cm in front of a convex mirror with a radius of curvature of 12 cm. Find the position of the image formed and give the characteristics of the image formed.

Given: $f = \frac{-12\ \text{cm}}{2} = -6.0\ \text{cm}$ $\quad$ ($f = \frac{r}{2}$, - because of convex mirror)

$D_o = 3.0$ cm

To find: D_i

Solution:

$$\frac{1}{D_o} + \frac{1}{D_i} = \frac{1}{f}$$

$$\frac{1}{3.0} + \frac{1}{D_i} = \frac{1}{-6.0}$$

$$\frac{1}{D_i} = -\frac{1}{6.0} - \frac{1}{3.0}$$

$$\frac{1}{D_i} = \frac{-1 - 2}{6.0}$$

$$\frac{1}{D_i} = \frac{-3}{6.0}$$

$$D_i = \frac{-6.0}{3}$$

$$D_i = -2.0\ \text{cm}$$

$$f = \frac{D_o \times D_i}{D_o + D_i}$$

$$-6.0 = \frac{3.0 \times D_i}{3.0 + D_i}$$

$$3.0 \times D_i = -6.0(3.0 + D_i)$$

$$3.0D_i = -18 - 6.0D_i$$

$$3.0D_i + 6.0D_i = -18$$

$$9.0D_i = -18$$

$$D_i = \frac{-18}{9.0}$$

$$D_i = -2.0\ \text{cm}$$

The image is virtual (D_i is negative), smaller in size ($\frac{D_i}{D_o}$ is less than unity) and erect (because image is virtual)

EXAMPLE 3

Find the focal length of a convex mirror which produces an image at a distance of 10 cm behind the mirror when the object is placed 15 cm in front of the mirror.

Given: $D_o = 15$ cm
$D_i = -10$ cm (Image virtual)

To find: $f = ?$

Solution:

$$\frac{1}{D_o} + \frac{1}{D_i} = \frac{1}{f}$$

$$\frac{1}{15} - \frac{1}{10} = \frac{1}{f}$$

$$\frac{2 - 3}{30} = \frac{1}{f}$$

$$\frac{-1}{30} = \frac{1}{f}$$

$$-30 = f$$

or $f = -30$ cm

$$f = \frac{D_o \times D_i}{D_o + D_i}$$

$$= \frac{15 \times -10}{(15 - 10)}$$

$$= \frac{-150}{5}$$

$$= -30$$

$f = -30$ cm

Focal length of the convex mirror is 30 cm.

EXAMPLE 4

A candle 3.0 cm high is placed 30 cm from a convex mirror of focal length 20 cm. Determine the height of the image.

Given: $f = -20$ cm
$D_o = 30$ cm
$S_o = 3$ cm

To find: $S_i = ?$

Solution:

$$\frac{1}{D_o} + \frac{1}{D_i} = \frac{1}{f}$$

$$\frac{1}{30} + \frac{1}{D_i} = \frac{-1}{20}$$

$$\frac{1}{D_i} = -\frac{1}{20} - \frac{1}{30}$$

$$\frac{1}{D_i} = \frac{-3 - 2}{60}$$

$$\frac{1}{D_i} = \frac{-5}{60}$$

$$D_i = -\frac{60}{5}$$

$$D_i = -12 \text{ cm}$$

or

$$f = \frac{D_o \times D_i}{D_o + D_i}$$

$$-20 = \frac{30 \times D_i}{30 + D_i}$$

$$30D_i = -20(30 + D_i)$$

$$30D_i = -600 - 20D_i$$

$$30D_i + 20D_i = -600$$

$$50D_i = -600$$

$$D_i = \frac{-600}{50}$$

$$D_i = -12 \text{ cm}$$

Magnification, $M = \frac{D_i}{D_o} = \frac{12}{30} = 0.40$ (no negative sign)

Also, $M = \frac{S_i}{S_o}$

$$S_i = M \times S_o$$
$$= 0.40 \times 3.0 \text{ cm}$$
$$= 1.2 \text{ cm}$$

Image will be 1.2 cm high.

PROBLEMS

1. An object is placed 10 cm in front of a concave mirror and the image is formed at the place 20 cm behind the mirror. Use mirror formula to find the focal length of the mirror and describe the characteristics of the image formed.

2. A convex mirror of radius of curvature 20 cm forms an image of an object at distance of 10 cm behind the mirror. Use mirror formula to find the position of the object.

3. An object is placed at a distance of 50 cm from a concave mirror whose radius of curvature is 20 cm. Use mirror formula to find the position of the image. Also find the magnification of the image.

4. A 20 cm high object is placed 15 cm in front of a convex mirror with a radius of curvature of 60 cm. Find the height of the image formed.

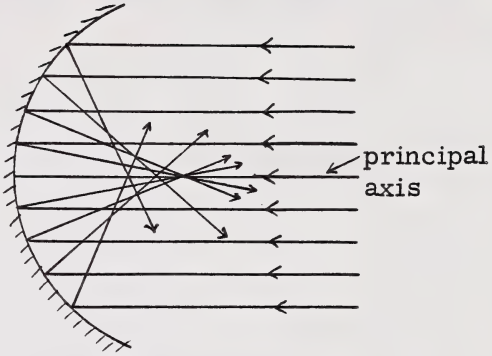
Spherical Aberration

Fig. E shows reflection from a spherical mirror. The incoming rays are parallel to the principal axis, but they do not all converge at the same point. The rays close to the axis come almost exactly to a point-focus, but the ones reflected from more distant positions on the mirror do not. This characteristic of spherical mirrors is called spherical aberration. To reduce this aberration you can use only the small center portion of a spherical mirror, blocking out the rest.

The perfect shape for focussing the parallel rays is a parabola as shown in Fig. F. Therefore another way of preventing spherical aberration is using parabolic mirrors. Parabolic mirrors are used in automobile headlights. In these the incandescent filament is placed at the principal focus of the parabolic mirror, resulting in a nearly parallel beam of light. A similar device is used in searchlights. Reflecting telescopes and solar ovens also use parabolic reflectors to focus light from distant objects.

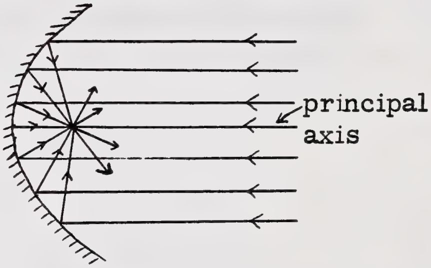
Spherical aberration may occur in both large and small mirrors. As long as the mirror is small compared with the focal length, the amount of spherical aberration is negligible.

Fig. E



Failure of rays parallel to the principal axis to meet at a common focus is called spherical aberration.

Fig. F



In a parabolic mirror, all rays parallel to the principal axis are reflected to the same focus.

QUESTIONS

1. What is spherical aberration?

____

____

____

2. What are two ways of reducing spherical aberration?

3. Describe two uses of a parabolic reflector.

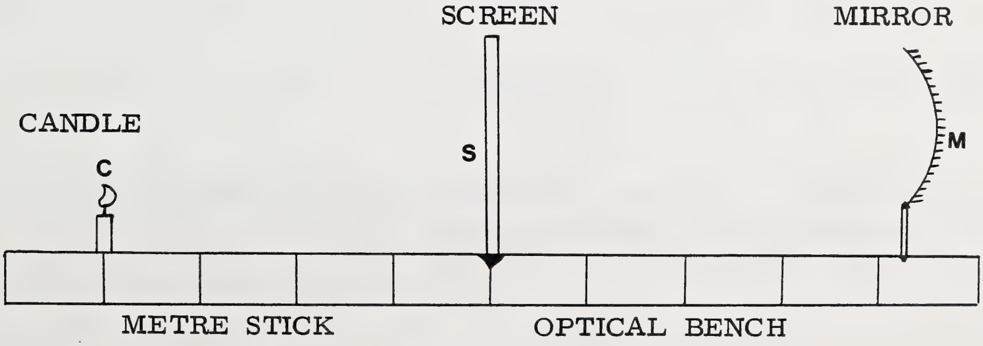
4. What should be the size of the mirror so that the spherical aberration is negligible?

EXPERIMENT #4 Reflection from a concave mirror

AIM: To find the focal length of a concave mirror.

APPARATUS:
Metre stick and support
Concave mirror
Mirror support
Screen support
Candle
15 cm × 15 cm screen

PROCEDURE:



1. Assemble the optical bench as shown in the diagram.
2. Place candle (C) at a distance of approximately 2 F from the mirror (M). (You know the rough focal length of the mirror from Experiment #3).
3. Adjust the position of the screen so that you get a bright image of the candle on the screen (S).
4. Note the positions of candle (C), mirror (M) and the screen (S) on the metre stick and record them in the table in the OBSERVATIONS section.
5. By placing the object[i.e. candle (C)]at a different position, find the position of the image by adjusting the position of the screen to get the bright image. Record the positions of candle (C), mirror (M) and screen (S) again.
6. Repeat this for at least four different positions of the candle.

OBSERVATIONS:

Rough focal length =

No.	Position of			Distance		$f = \frac{D_o \times D_i}{D_o + D_i}$
	Mirror(M)	Candle(C)	Screen(S)	$MC = D_o$	$MS = D_i$	
1						
2						
3						
4						

Average focal length =

ANALYSIS AND CONCLUSION:

____

____

____

Lesson Summary

- Image formed by a convex mirror is always virtual, erect and smaller in size.
- Mirror formula $\frac{1}{D_o} + \frac{1}{D_i} = \frac{1}{f}$ can be used for either convex or concave mirrors.
- f for a convex mirror is taken negative.
- D_i for a virtual image is taken negative.
- Magnification, $M = \frac{S_i}{S_o} = \frac{D_i}{D_o}$
- No negative sign is required for D_i in $M = \frac{D_i}{D_o}$.
- Spherical aberration is the inability of a spherical mirror to focus all the incident parallel rays to one point.
- Spherical aberration can be reduced using small section of a mirror or can be eliminated by using parabolic mirrors.

CONGRATULATIONS! You have completed Lesson 3C. Please check to make sure all questions are completed and no careless errors have been made. Then submit the lesson immediately for correction, rather than saving up several lessons before mailing.

End of Lesson 3C

LESSON RECORD FORM

3260 PHYSICS 30

Elective C

Revised 88/11

FOR STUDENT USE ONLY

Date Lesson Submitted

____

Time Spent on Lesson

____

(If label is missing
or incorrect)

File Number

____

Lesson Number _______________

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Additional Grading E/R/P Code: ________

Mark: ________

Graded by: ________

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ALBERTA CORRESPONDENCE SCHOOL

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1. BEFORE MAILING YOUR LESSONS, PLEASE SEE THAT:

(1) All pages are numbered and in order, and no paper clips or staples are used.
(2) All exercises are completed. If not, explain why.
(3) Your work has been re-read to ensure accuracy in spelling and lesson details.
(4) The Lesson Record Form is filled out and the correct lesson label is attached.
(5) This mailing sheet is placed on the lesson.

2. POSTAGE REGULATIONS

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3. POSTAGE RATES

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Take your lesson to the Post Office and have it weighed. Attach sufficient postage and a **green first-class sticker to the front of the envelope, and seal the envelope. Correspondence lessons will travel faster if first-class postage is used.**

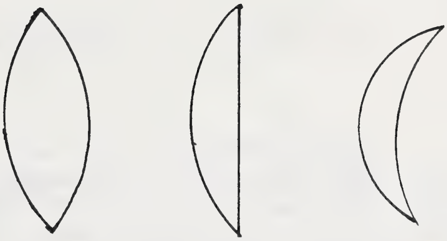
Try to mail each lesson as soon as it has been completed.

When you register for correspondence courses, you are expected to send lessons for correction regularly. Avoid sending more than two or three lessons in one subject at the same time.

REFRACTION THROUGH LENSES

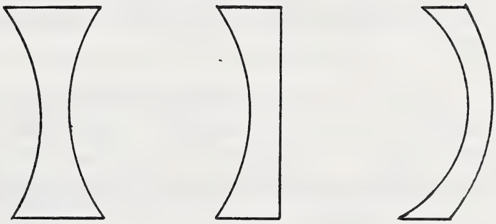
Convex lenses or converging lenses bring light rays together, while concave lenses or diverging lenses spread light rays apart. The two are easily distinguished by their shape. Convex lenses are thickest at the centre as shown in Fig. A. Diverging lenses are thinnest at the centre as shown in Fig. B. Fig. A shows three types of convex lenses. The one to the left has two curved surfaces and is called a double convex lens; the one in the middle has one convex and one plane surface and is called a plano-convex lens; the one to the right has one concave surface and one convex surface, the curvature of the convex surface is greater, therefore it acts as a convex lens and is called a concavo-convex lens. Similarly Fig. B shows three types of concave lenses. The one to the left is called the double concave lens, the one in the middle is called the plano-concave lens and the one to the right is called the convexo-concave lens. You will remember that a spherical mirror has an axis and a focus. So does a lens. The meaning of these terms is made clear in Fig. C-i. The principal axis of a lens is the line joining the centers of curvature of the two surfaces or if one surface is a plane, the line from the center of curvature of the curved surface perpendicular to the plane surface. Optical center of a lens is the point on the principal axis, such that rays passing through it do not suffer any change in direction. For all practical purposes, geometrical center of the lens can be taken as the optical center of the lens as shown in Fig. C-i.

Fig. A



Convex lenses

Fig. B



Concave lenses

Fig. C-i

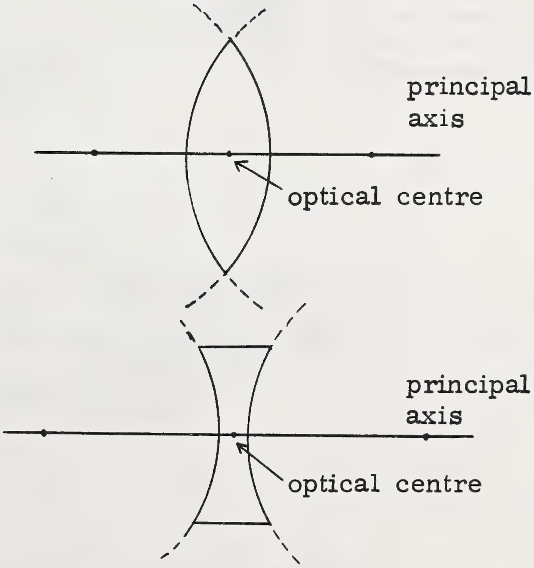
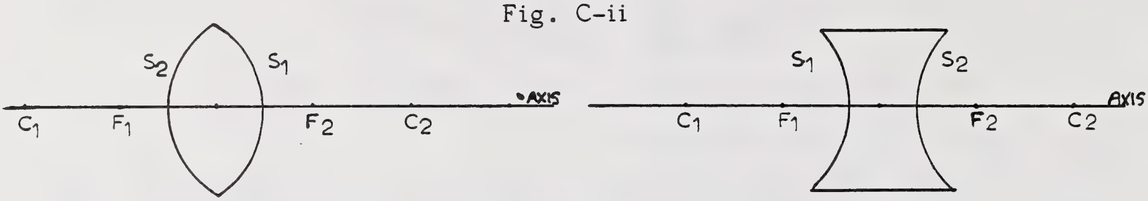


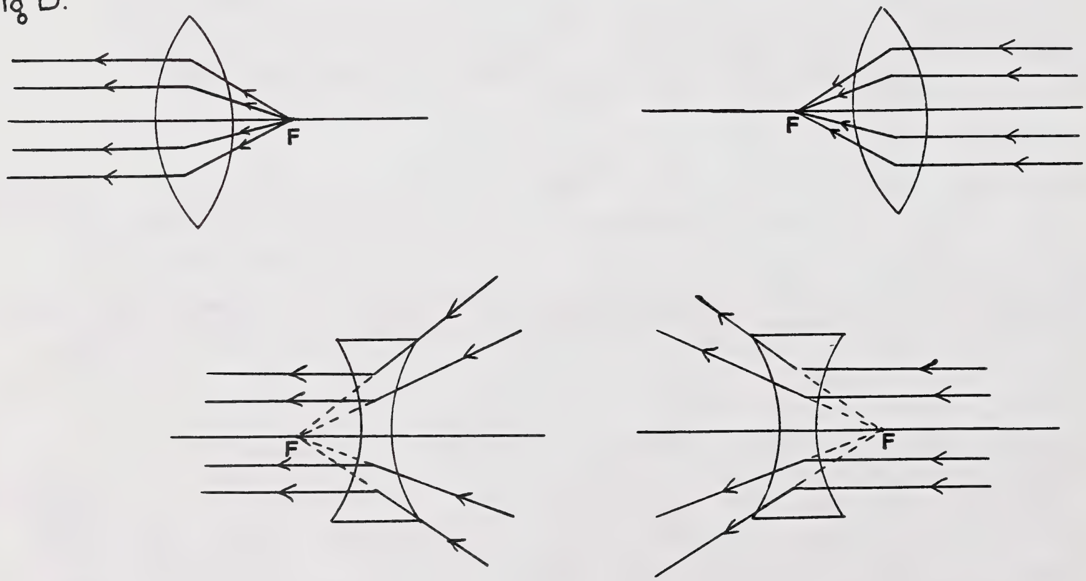
Fig. C-ii



In Fig. C-ii, C_1 is the center of the sphere of which the spherical surface s_1 is a part and C_2 is the center of the sphere of which the spherical surface s_2 is a part. The points C_1 and C_2 are called the centers of curvature of the two surfaces. The line joining the centers of curvature is called the axis of the lens. The principal focus, F, of a lens is the point at which rays originally parallel to the axis converge, or the point from which they seem to diverge. A lens has two principal foci, one on either side, since light will pass through it in either direction. Distance from the center of the lens to either principal focus is called the focal length of the lens.

When a beam of parallel rays of light falls on a lens in a direction parallel to its principal axis, the rays, after refraction through the lens, converge to a point or appear to diverge from a point on the principal axis. This point is called the principal focus of the lens. See Fig. D.

Fig D.



For a thin lens, the focal length is the distance from either principal focus to the center of the lens. For a thick lens, the situation is more complicated, but you will not be concerned with thick lenses in this course.

Lens Formula

The lens formula is used to find the position of the image for an object at a given distance or vice versa. The formula is:

$$\frac{1}{D_o} + \frac{1}{D_i} = \frac{1}{f} \qquad \text{or} \qquad f = \frac{D_o \times D_i}{D_o + D_i}$$

Where D_o is the distance of the object from the center of the lens, D_i is the distance of the image from the center of the lens and f is the focal length of the lens. The rules for using this formula are:

1. For a convex lens, f is positive and for a concave lens f is negative.
2. D_o is always positive.
3. D_i is positive if the image is real, which means it is on the opposite side of the lens from the object. D_i is negative if the image is virtual, which means it is on the same side as the object.

After a refraction through a lens, the size of an image can be smaller, equal to, or greater than the object. Magnification is used to express this and is defined as follows:

$$\text{Magnification} = \frac{\text{Size of image}}{\text{Size of object}}$$

$$= \frac{\text{distance of image}}{\text{distance of object}}$$

$$\text{or} \quad M = \frac{D_i}{D_o}$$

To find magnification both D_i and D_o are always considered positive. If the magnification is greater than 1, the image is larger and if it is less than 1, the image is smaller than the object.

EXAMPLE 1

An object is placed 20.0 cm from a concave lens with a focal length of 50.0 cm. Find the position of its image.

Given: $D_o = 20.0$ cm

$f = -50.0$ cm (- because it is a concave lens)

To find: $D_i = ?$

Solution:

$$\frac{1}{D_o} + \frac{1}{D_i} = \frac{1}{f}$$

$$\frac{1}{D_i} = \frac{1}{f} - \frac{1}{D_o}$$

$$\frac{1}{D_i} = -\frac{1}{50} - \frac{1}{20}$$

$$\frac{1}{D_i} = \frac{-2 - 5}{100}$$

$$\frac{1}{D_i} = \frac{-7}{100}$$

$$D_i = \frac{-100}{7} = -14.3 \text{ cm}$$

or

$$f = \frac{D_o \times D_i}{D_o + D_i}$$

$$-50 = \frac{20 \times D_i}{20 + D_i}$$

$$-50(20 + D_i) = 20D_i$$

$$-1000 - 50\ D_i = 20\ D_i$$

$$-1000 = 20\ D_i + 50\ D_i$$

$$-1000 = 70\ D_i$$

$$D_i = \frac{-1000}{70} = -14.3 \text{ cm}$$

The image is 14.3 cm from the lens and is on the same side as the object. It is a virtual image. (Answer has 3 S.D. because the least accurate data contain 3 S.D.)

EXAMPLE 2

A convex lens has a focal length of 50 cm. An object is placed 200 cm from the lens. Where is the image formed? Is it virtual or real?

Given: $f = +50$ cm

$D_o = 200$ cm

To find: $D_i = ?$

Solution:

$$\frac{1}{D_o} + \frac{1}{D_i} = \frac{1}{f}$$

$$\frac{1}{D_i} = \frac{1}{f} - \frac{1}{D_o}$$

$$\frac{1}{D_i} = \frac{1}{50} - \frac{1}{200}$$

$$\frac{1}{D_i} = \frac{4 - 1}{200}$$

$$\frac{1}{D_i} = \frac{3}{200}$$

$$D_i = \frac{200}{3} = 66.7$$
$$= 67 \text{ cm}$$

or

$$f = \frac{D_o \times D_i}{D_o + D_i}$$

$$50 = \frac{200 \times D_i}{200 + D_i}$$

$$50(200 + D_i) = 200\ D_i$$

$$10\ 000 + 50\ D_i = 200\ D_i$$

$$10\ 000 = 200\ D_i - 50\ D_i$$

$$D_i = \frac{10\ 000}{150} = 66.7$$
$$= 67 \text{ cm}$$

Description: The image is real and is 67 cm from the lens.

(Answer was rounded off to 2 S.D. because least accurate data contains 2 S.D.)

EXAMPLE 3

A concave lens of focal length 20 cm is 30 cm away from an object. What will be the position of the image? Also find the magnification of the image.

Given: $f = -20$ cm (- because it is a concave lens)

$D_o = 30$ cm

To find: $D_i = ?$

Solution:

$$\frac{1}{D_o} + \frac{1}{D_i} = \frac{1}{f}$$

$$\frac{1}{D_i} = \frac{1}{f} - \frac{1}{D_o}$$

$$\frac{1}{D_i} = -\frac{1}{20} - \frac{1}{30}$$

$$\frac{1}{D_i} = \frac{-3 - 2}{60}$$

$$\frac{1}{D_i} = -\frac{5}{60}$$

$$D_i = -\frac{60}{5} = -12 \text{ cm}$$

$$f = \frac{D_o \times D_i}{D_o + D_i}$$

$$-20 = \frac{30 \times D_i}{30 + D_i}$$

$$-20(30 + D_i) = 30\ D_i$$

$$-600 - 20\ D_i = 30\ D_i$$

$$-600 = 30\ D_i + 20\ D_i$$

$$-600 = 50\ D_i$$

$$D_i = -\frac{600}{50} = -12 \text{ cm}$$

$$\text{Magnification, } M = \frac{D_i}{D_o} = \frac{12}{30} = 0.40$$

(Magnification is considered positive, so 12 is used instead of -12.)

The image formed is virtual, smaller than the object and is 12 cm from the lens. (Answer contains the same number of S.D. as the least accurate data)

PROBLEMS

1. A camera lens has a focal length of 10 cm. What should be the distance of the lens from the film in order to take a picture of an object 1.0 m away? (A camera uses a convex lens.)

2. A concave lens has a focal length of 30 cm. What will be the position of the image if an object is placed 20 cm in front of the lens?

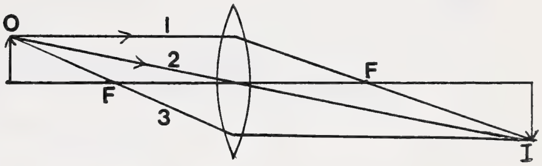
3. A convex lens has a focal length of 20 cm. The object distance is 10 cm. What is the position of the image, and what type of image is it?

4. A motion picture projector uses a convex lens with a focal length of 5.0 cm to project an image on a screen 4.0 m away. How far from the lens must the film be in order for the focus to be clear? What is the magnification?

Geometrical location of an image in a lens

You can locate images made by lenses as you did with mirrors. Three rays used here are shown in Fig. E.

Fig. E



1. The ray parallel to the principal axis, passes through F on the other side of the lens.
2. The ray passing through the optical center of the lens, continues on in a straight line.
3. The ray that goes through the principal focus on the near side of the lens.

   This ray emerges parallel to the principal axis.

Out of these three rays mentioned above you can choose any two rays starting from a point and where these two rays intersect after refraction, that will be the image of that point e.g. I is the image of O in Fig. E. Remember you do not have to draw all three rays to locate I. The intersection of any two rays (e.g. 1 & 2; 2 & 3; 1 & 3) will locate the position of I.

Besides choosing two rays out of the three mentioned above, you have to go through the following steps for the location of the image in a concave mirror.

Steps in image location by construction:

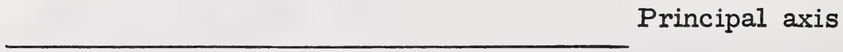
1. Choose a suitable scale for your drawing.
2. Draw the principal axis.
3. Locate the lens and the two principal foci according to the scale.
4. On the principal axis, and at right angles to it, draw an arrow to represent the object at the given distance from the lens.
5. Locate the top of the image by drawing two rays out of the three rays suggested above.
6. From this point draw a perpendicular to the principal axis. This line represents the image.

We will take a sample construction using these steps.

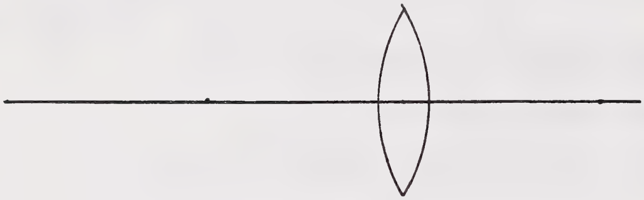
Example: Sketch a scale diagram for the location of the image of an object placed 60 cm in front of a convex lens of focal length 30 cm.

Step 1 Let 1 cm = 10 cm

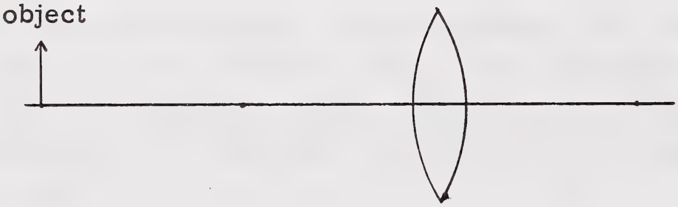
Step 2



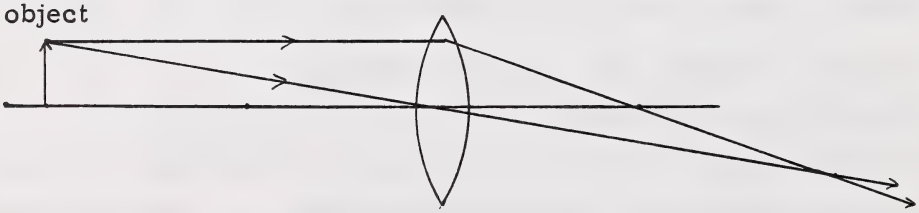
Step 3



Step 4



Step 5



Step 6

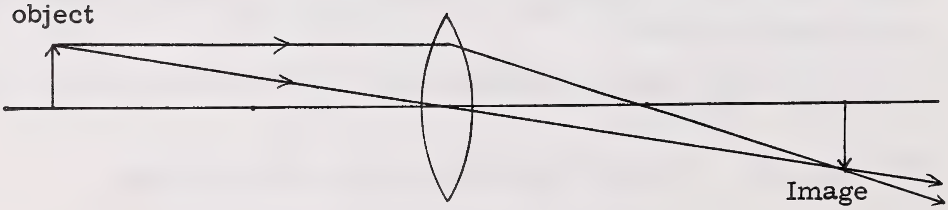


Fig. F to Fig. K show the formation of the image after refraction from a convex lens. Study these figures carefully. Later you will compare these predicted images and their characteristics with the actual observations made in Experiment #5. The convex lens shown has a focal length of 60 cm.

Fig. F

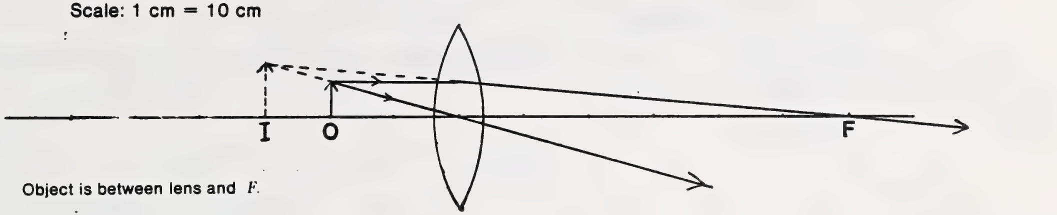
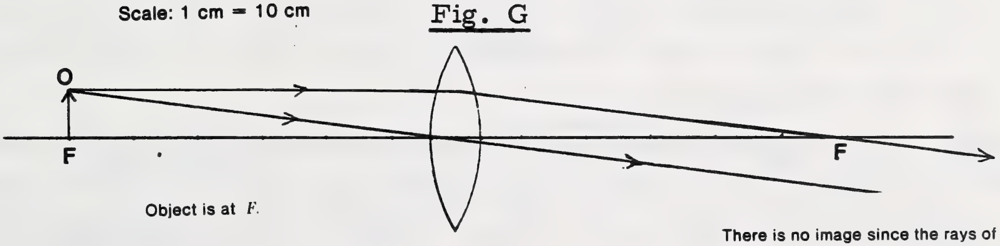


Image is virtual, erect, enlarged. You use a convex lens in this way for a magnifying glass.

Fig. G



There is no image since the rays of light are parallel. If a light source were placed at the focus, a parallel beam of light would emerge.

Fig. H

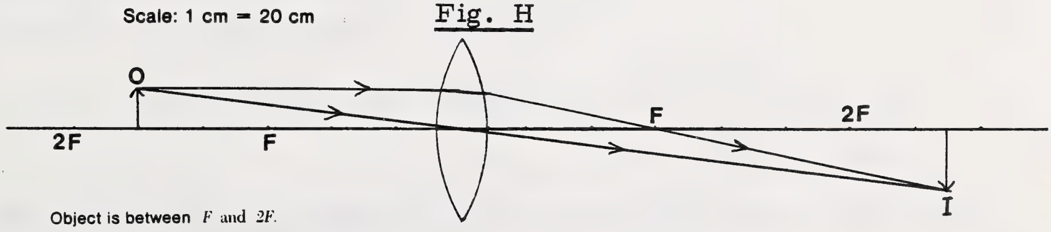
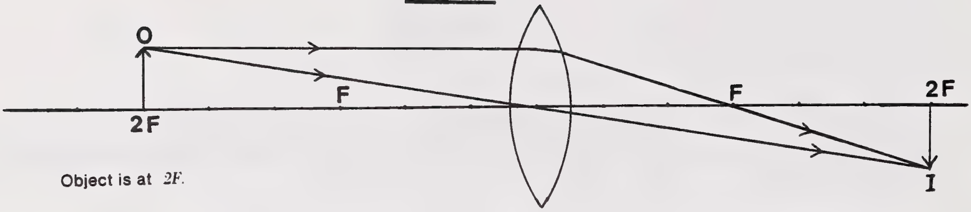


Image is real, inverted, enlarged. A motion picture or slide projector uses a lens in this way. The operator must put the film in the machine upside down in order to project it correctly. The nearer the film is to F, the larger and farther away the image will be. A photographic enlarger also uses a lens in this way.

Scale: 1 cm = 20 cm

Fig. I

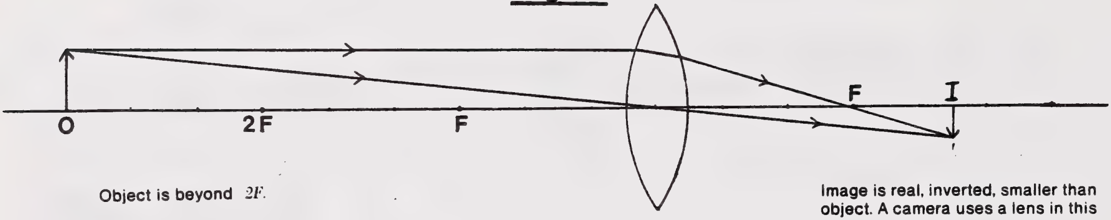


Object is at *2F*.

Image is real, inverted, same size as object. A portrait camera might use a lens in this way.

Scale: 1 cm = 20 cm

Fig. J

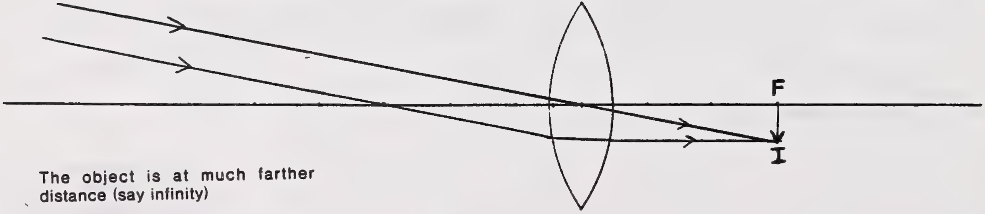


Object is beyond *2F*.

Image is real, inverted, smaller than object. A camera uses a lens in this fashion to form a small image on the film.

Scale: 1 cm = 20 cm

Fig. K

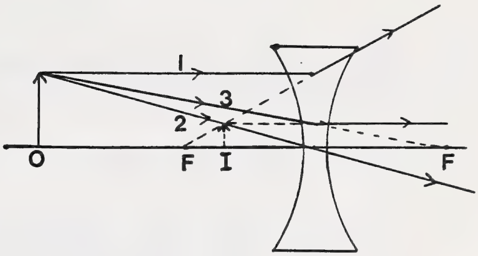


The object is at much farther distance (say infinity)

Image is real, inverted, and smaller than the object.

Location of image formed by a concave lens

Fig. L



The image formed by a concave lens can be located much the same way as for a convex lens, except that the ray (1) parallel to the axis diverges as if it had come from the nearer principal focus, and the ray (3) that heads for the farther principal focus leaves the lens parallel to the axis. The ray (2) passes through the optical center without any change in direction. Irrespective of the position of the object, the image formed by a concave lens will always be virtual, erect and smaller in size.

Spherical Aberration

Lenses, as well as spherical mirrors, have spherical aberration. Spherical aberration is a defect of spherical lenses caused by the failure of rays of light far from the axis to focus at the same point as those closer to it.

You can all but eliminate this problem by blocking out the rays that go through the edge of the lens, leaving only the ones in the middle. Spherical aberration in instruments using lenses can also be decreased by using a proper combination of two or more lenses. Often these lenses elements are cemented together.

QUESTIONS

1. What is a spherical lens?

____

____

2. Distinguish between a convex and a concave lens with respect to their shape.

____

____

3. Distinguish between convex and concave lenses with respect to the effect they have on light.

____

____

4. Draw a diagram of a convex lens illustrating what is meant by the axis.

5. What type of lens has a concave surface on one side and a convex surface on the other side but is thicker in the center than at the edges?

____

6. A convex lens has a focal length of 50 cm. An object is placed 200 cm from the lens. Find the position of the image formed using a scale diagram. Also define the characteristics of the image formed.

7. Draw a scale diagram to find the position of the image of an object placed 20 cm in front of a convex lens of focal length 50 cm. Also describe the image.

8. An object is placed 30 cm from a concave lens of focal length 60 cm. Draw a scale diagram to locate the image formed and describe the image formed.

9. What is spherical aberration?

____

____

10. What are the two ways to control spherical aberration?

____

____

EXPERIMENT #5 Refraction from a convex lens

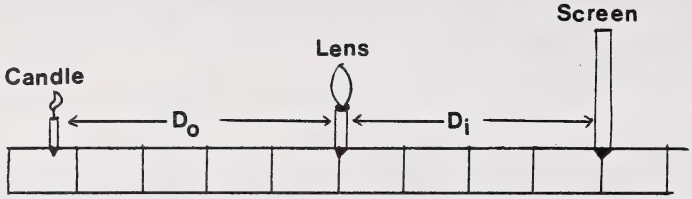
AIM: To find the focal length of a convex lens

APPARATUS:
Convex lens
Lens holder
Metre stick and supports (optical bench)
Screen (15 cm × 15 cm cardboard)
Screen support
Candle (object)
Candle holder

PROCEDURE:

1. Locate the image of the sun as a bright spot on a sheet of cardboard and measure the distance from the lens to the bright spot on the cardboard.

2. Cut the candle so that when it is set in the holder and mounted on the optical bench, it will be the same height as the centre of the lens when it is mounted on the bench in the lens holder. Use a piece of stiff cardboard in the screen holder as a screen. Do this investigation with a lighted candle as the object in a darkened room.



3. Arrange the apparatus as shown in the diagram.
4. Move the screen back and forth until a clear image of the candle is formed on it.
5. Note the characteristics of the image formed and describe it in the table in OBSERVATIONS section.
6. Then turn on the room light and measure D_o and D_i and note them in the table in OBSERVATIONS section.
7. Take at least five sets of measurements by changing the position of the candle every time, thereby changing D_o and repeating steps 4 to 6 every time.
8. Find the focal length of the lens, using the lens formula $\frac{1}{f} = \frac{1}{D_o} + \frac{1}{D_i}$ or $f = \frac{D_o \times D_i}{D_o + D_i}$.

OBSERVATIONS:

f found by locating image of sun as a bright spot = cm

	D_o (cm)	D_i (cm)	$f = \frac{D_o \times D_i}{D_o + D_i}$	f (cm)	Characteristics of the image
1					
2					
3					
4					
5					

AVERAGE f = ________ cm

ANALYSIS AND CONCLUSIONS:

1. The focal length of the convex lens is ________________.

2. The image formed in all cases is real/virtual ________________.

3. Why could you not get the other kind of image than mentioned in #2 above.

____

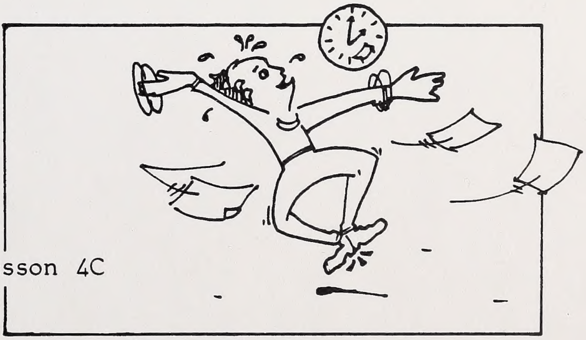
____

Lesson Summary

- There are two types of lenses — concave and convex.
- Concave lenses are diverging lenses while convex lenses are converging lenses.
- Image formed by a concave lens is always virtual, erect and smaller in size.
- Image formed by a convex lens can be real or virtual, smaller or larger in size and can be erect or inverted, depending upon the position of the object relative to the focal length.
- Location of the image in any lens can be found out either by using the lens formula $\frac{1}{D_o} + \frac{1}{D_i} = \frac{1}{f}$ or by using geometrical construction method.

  Another version of the above formula is $f = \frac{D_o \times D_i}{D_o + D_i}$

CONGRATULATIONS! You have completed Lesson 4C. Please check to make sure all questions are completed and no careless errors have been made. Then submit the lesson immediately for correction.



End of Lesson 4C

N.L.C. - B.N.C.
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